EQL Report No. 17-C

SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

Part C
Coastal Sediment Delivery by Major Rivers in Southern California

by

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PREFACE

In southern California the natural environmental system involves the continual relocation of sedimentary materials. Particles are eroded from inland areas where there is sufficient relief and precipitation. Then, with reductions in hydraulic gradient along the stream course and at the shoreline, the velocity of surface runoff is reduced and there is deposition. Generally, coarse sand, gravel and larger particles are deposited near the base of the eroding surfaces (mountains and hills) and the finer sediments are deposited on floodplains, in bays or lagoons, and at the shoreline as delta deposits. Very fine silt and clay particles, which make up a significant part of the eroded material, are carried offshore where they eventually deposit in deeper areas. Sand deposited at the shoreline is gradually moved along the coast by waves and currents, and provides nourishment for local beaches. However, eventually much of this littoral material is also lost to offshore areas.

Human developments in the coastal region have substantially altered the natural sedimentary processes, through changes in land use, the harvesting of natural resources (logging, grazing, and sand and gravel mining); the construction and operation of water conservation facilities and flood control structures; and coastal developments.

In almost all cases these developments have grown out of recognized needs and have well served their primary purpose. At the time possible deleterious effects on the local or regional sediment balance were generally unforeseen or were felt to be of secondary importance.

In 1975 a large-scale study of inland and coastal sedimentation processes in southern California was initiated by the Environmental Quality Laboratory at the California Institute of Technology and the Center for Coastal Studies at Scripps Institution of Oceanography.

This volume is one of a series of reports from this study. Using existing data bases, this series attempts to define quantitatively inland and coastal sedimentation processes and identify the effects man has had on these processes. To resolve some issues related to long-term sediment management, additional research and data will be needed.

In the series there are four Caltech reports that provide supporting studies for the summary report (EQL Report No. 17). These reports include:

EQL Report 17-A -- Regional Geological History

EQL Report 17-B -- Inland Sediment Movements by Natural Processes

EQL Report 17-C -- Coastal Sediment Delivery by Major Rivers in Southern California

EQL Report 17-D -- Special Inland Studies

Additional supporting reports on coastal studies (shoreline sedimentation processes, control structures, dredging, etc.) are being published by the Center for Coastal Studies at Scripps Institution of Oceanography, La Jolla, California.

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Report 17-C

COASTAL SEDIMENT DELIVERY BY MAJOR RIVERS IN SOUTHERN CALIFORNIA

C1 Sediment Transport and Southern California

C1.1 Introduction

Over the past 100 years extensive urbanization has had a severe influence on the landscape of southern California. In particular, the rivers and streams have undergone extensive development, primarily for water supply and flood control purposes. This report examines the effects of various man-made systems on the sediment yields of the 11 largest drainage basins in the study area. It is hoped that by understanding the effects of the present systems we will be better able to make future management decisions.

In Report 17-B, two natural interfaces or boundaries through which there is sediment flux were identified for primary consideration in defining inland sediment movements throughout the study area. The first boundary is the general interface between upland erosional areas and the coastal plains, and the second boundary is the shoreline. Using basin parameters, a regression model was used to estimate annual sediment transport through these boundaries for all drainage units except 11 major drainage basins.

For these latter basins (the subject of this report), historical streamflow and sediment discharge data collected near the coast are sufficient to obtain estimates of annual sediment yield to the shoreline. By treating these 11 basins in detail, over 80 percent of the drainage area that supplies sediments to the Pacific Ocean can be examined. With regard to the 11 basins, the specific purposes of this report are:

1. To provide estimates of the actual sediment yield and the sediment yield that would have occurred under natural uncontrolled conditions for the eight drainage basins with moderate development.

2. To discuss the possible effects that man has imposed on the sediment delivery of the three remaining, extensively developed basins, with an outlook toward future intensive studies of these basins; and to give recommendations for future work.

3. To provide information on the availability, extent, and distribution of streamflow and sediment data for all the basins. (Some of these data will be presented in Section C19, and other data used to characterize the various basins will be presented with the text.)

C1.2 Study Area

The study area shown in Fig. C1-1 has been divided into 24 major drainage units, indicated in Fig. C1-1 and identified in Table C1-1. Fifty-three percent of the total drainage area of over 32,000 km^2 is controlled by major water retention structures. In addition, the hydrologic and sedimentary systems have been altered by diversion facilities, channelization, sand and gravel mining operations, percolation basins, ground water pumping, irrigation ditches, and other man-made systems.

For the purposes of this report, each of the 24 drainage units will be considered as one of four distinct types:

Drainage Groups. These units represent groups of smaller basins which debouch directly into the Pacific Ocean. All of the individual basins within these units have drainage areas that are less than 500 km^2. Most of the individual basins, such as all of those in the Santa Inez Mountains group (A)* are on the order of tens of km^2. Essentially, these units represent the areas between the major river basins of the study area. A discussion of the sediment yield from these units can be found in Report 17-B. In all, 10 of the 24 units shown in Fig. C1-1 are groups of smaller basins. Because this report is intended to explore man's

*Letters in parentheses indicate map symbol on Fig. C1-1.

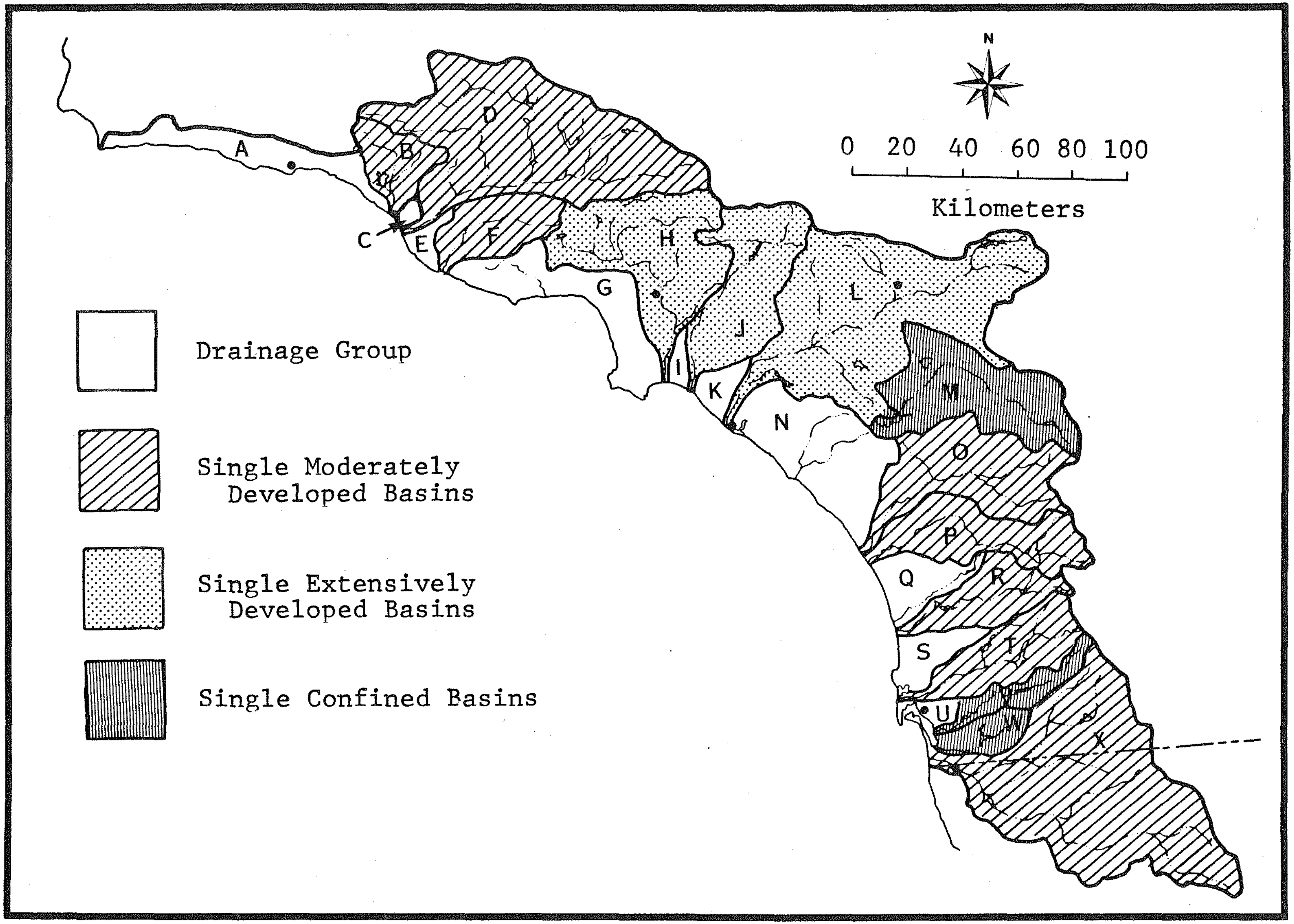

Figure C1-1 Southern California Study Area showing drainage unit classifications units are identified by letter and classifications are defined in Table C1-1.

TABLE C1-1

Major Drainage Units in the Sediment Management Study Area

Map Symbol	Principal Basin or Group of Small Basins	Classification[c]	Controlled Drainage Area of Principal Basins[a] sq. km	Area sq. km	Percent Controlled Area of Principal Basins
A	Santa Ynez Mountains Group	G	--	901	--
B	Ventura River Basin	SMD	243	585	42
C	Ventura Group	G	--	52	--
D	Santa Clara River Basin	SMD	1,527	4,219	37
E	Oxnard Group	G	--	159	--
F	Calleguas Creek Basin	SMD	--	837	--
G	Santa Monica Mountains Group	G	166	1,493	11
H	Los Angeles River Basin	SED	866[b]	2,155	40
I	Long Beach Group	G	--	120	--
J	San Gabriel River Basin	SED	1,400	1,663	84
K	Huntington Beach Group	G	--	234	--
L	Santa Ana River Basin	SED	3,950	4,406[d]	90
M	Lake Elsinore Basin	SC	1,989	1,989[e]	100
N	Laguna Hills Group	G	--	1,737	--
O	Santa Margarita River Basin	SMD	958	1,927	50
P	San Luis Rey River Basin	SMD	531	1,450	37
Q	Escondido Creek Group	G	--	568	--
R	San Dieguito River Basin	SMD	785	896	88
S	San Clemente Canyon Group	G	--	437	--
T	San Diego River Basin	SMD	686	1,119	61
U	San Diego Group	G	--	157	--
V	Sweetwater River Basin	SC	471	567	83
W	Otay River Basin	SC	255	370	69
X	Tijuana River Basin	SMD	3,175	4,483	72
	TOTALS		17,002	32,524	53

[a]Calculated by adding the drainage areas controlled by the major water retention structures that are furthest downstream in each basin.

[b]Whittier Narrows Flood Control Basin controls both Los Angeles and San Gabriel Rivers. This estimate assumes that 35 km^2 of the drainage area controlled by the Whittier Narrows structure lies within the Los Angeles River drainage basin.

[c]G - Drainage Group
SED - Single Extensively Developed Basins
SC - Single Confined Basins
SMD - Single Moderately Developed Basins

[d]Excludes Lake Elsinor Basin (M).

[e]Closed interior basin. Overflow into Santa Ana River basin has not occurred since 1916.

influence on the sediment deliveries of the major rivers, no further mention will be made of these units.

Confined Basins. These are units that are drained by a single river system, but do not deliver sediment directly to the Pacific Ocean. The three drainage units in this category are the Lake Elsinore basin (M) and the Sweetwater (V) and the Otay (W) river basins. The first of these basins is drained by the San Jacinto River into Lake Elsinore. The lake serves as the final sink for the runoff in the basin, except during extreme events when Lake Elsinore overflows into the Santa Ana River basin (L). (The last recorded overflow occurred in 1917.) The second and third units in this category are drained by the Sweetwater and the Otay rivers into the south end of San Diego Bay. Although these rivers deliver sediments to the coastal zone, at this stage in the geologic process the sediments are primarily confined to San Diego Bay and do not reach the Pacific Ocean. Since the three units in this category do not actively supply sediments to ocean beaches, there will be no further mention of these drainage basins.

Single Basins with Moderate Development. This group of eight basins is the subject of sections C2 through C11 of this report The basins in this group are identified by the letters used in Fig. C1-1. They are, from the north:

B. Ventura River basin
D. Santa Clara River basin
F. Calleguas Creek basin
O. Santa Margarita River basin
P. San Luis Rey River basin
R. San Dieguito River basin
U. San Diego River basin
X. Tijuana River basin

With the exception of Calleguas Creek, all of these basins have at least one major water retention structure. The Santa Clara basin, for example, has four such structures and a major diversion facility. As a first approach to understanding man's influence on the sediment delivered from the basins in this category, one may study the effect of the water retention and diversion facilities. This approach, as used in this report, discounts other aspects of man's activities, such as land use changes, which are considered to be of less importance in this class of drainage units.

Single Basins with Extensive Development. The three drainage units in this category are the Los Angeles (H), San Gabriel (J), and Santa Ana (L) river basins. With their headwaters in the San Gabriel and San Bernardino mountains, these rivers flow over the large alluvial deposit known as the Los Angeles basin. In order to understand man's effect on the sediment delivery of these river systems, it is necessary to study the effects of land use changes and the extensive urbanization in the Los Angeles basin. In particular, these rivers have undergone extensive channelization to the point where much of the Los Angeles River system has become a network of concrete-lined flood control channels. These extensively developed basins are examined in sections C12 through C15.

C1.3 Scope

The analyses presented herein were undertaken to provide first-order estimates of the sediment yields of the major rivers of southern California, and to understand man's role in altering those yields. Dams and diversion facilities have been identified as the major human influences for study on the moderately developed basins. Other effects, such as land use changes, fire frequency and distribution changes, the construction of levees and the presence of sand and gravel operations, have not been specifically included in the calculations for the moderately developed basins. On some basins these effects may be of considerable importance (separate studies of these effects can be found in other reports). For example, the presence of levees on the lower reach of a river may concentrate high flows, thereby increasing the sediment yield. On the other hand, sand and gravel mining operations will tend to trap sedimentary materials, thereby reducing sediment yield. To alert the reader of the possibility of these effects, a detailed map of the lower reach of each river has been provided. While we recognize that dams are of vital importance to the people of California, we feel that it is also necessary to understand the role of these dams in changing the sediment budget.

The complexity of human interference with the natural order on the extensively developed basins has made it impossible to single out one factor which influences sediment yield. To properly understand these basins, the Los Angeles, San Gabriel and Santa Ana river basins, it is necessary to develop a model which would include the effects of dams, channelization, urbanization, etc. Such a model was considered to be beyond the scope of this study. However, it is possible to present a review of available data and some preliminary estimates based on that data.

This report provides the details of technical calculations. Many of the tables are actually the result of statistical analysis in the form of computer output, in which case no round off has been performed. Elsewhere, it has been decided to round o-f to a convention of three significant figures. In most cases the accuracy of the results may not warrant three significant figures, and it is therefore left to the reader to make further reductions.

An attempt was made to analyze the moderately developed basins in a consistent fashion. However, each basin provided its own unique problems and requirements, and a separate treatment of each basin was therefore required. The text has been presented in such a way as to accommodate the reader who may be primarily interested in only one or more of the river systems. The reader may review the introductory material and definitions in section C1, the outline of the basic analytical procedure in section C2, the section on the particular basin of interest, and the summary of results for the moderately developed basins in section C11. Unfortunately, a certain amount of repetition in sections concerning individual basins has been unavoidable.

Certain dams, depending on their construction and size, act as partial containment structures for sediment, while others provide nearly total containment. To determine the effect of a dam on the sediment yield of a river from the amount of material captured, one must know the trap efficiency and the degree of scour or deposition occurring downstream from the dam. Rather than estimate these factors, indirect methods have been used whenever possible, to calculate sediment yield reductions. Where containment records are available, comparisons have been made with the results of the indirect methods, as a check on the latter methods.

C1.4 Sediment Delivery and Littoral Cells

The coast of southern California can be divided into five "littoral cells" (Inman and Brush, 1973), as shown in Fig. C1-2. These cells may in some respects be considered as independent units. They act as the primary receptacles for sediments delivered by the various drainage units. The sediments are then moved along the shoreline by coastal processes and eventually are moved offshore, by either flowing down submarine canyons or other Mechanisms. The moderately developed basins deliver their

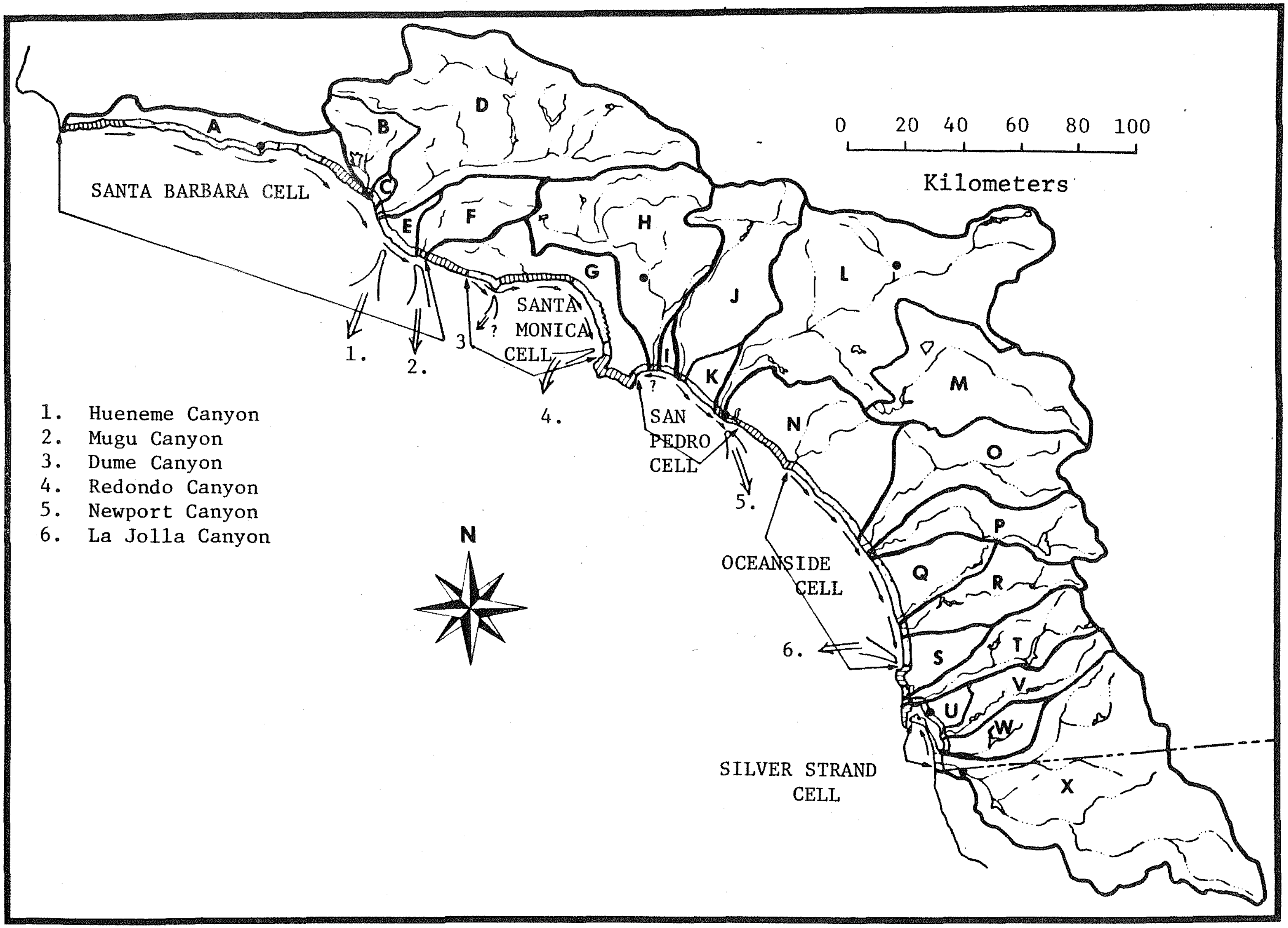

Figure C1-2 Littoral cells in southern California.

sediments to the Santa Barbara, Oceanside, and Silver Strand cells. The extensively developed basins currently deliver their sediments to the San Pedro cell. However, under natural circumstances, the course of the Los Angeles River probably alternated between the Santa Monica and the San Pedro cells. For a detailed study of shoreline sedimentation processes, see Part E in this series.

C1.5 Definition of Terms

The following terms related to streamflow and other hydrologic data have been used in this report. The following description of terms is based on definitions given by the USGS (1976, pp. 1-13).

Base flow sometimes called groundwater flow or dry-weather flow, occurs when the water table intersects the stream channels of a basin. In this report, any mean daily flows that are less than a cut-off value (selected by inspection of annual flow sequences for a particular station) will be classified as base flows.

Bed material is the unconsolidated material of which a stream bed, lake, pond, reservoir, or estuary bottom is composed.

Bed-material (bed-sediment) load is that part of the sediment load which is composed of particle sizes that are found in appreciable quantities in the stream bed. The bed-material load consists of the bedload and the suspended sand.

Discharge (flow) is the rate at which water (or more broadly, total fluids, plus suspended sediment) passes a given point, expressed in volume per unit time (e.g., m^3/s).

Mean daily discharge (flow) is the total volume of water discharged (e.g., in m^3) in any given day divided by 86,400 seconds.

Instantaneous discharge is the discharge at a particular instant of time.

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point. Figures of drainage area therein include all closed basins, or non-contributing areas, within the area unless otherwise noted.

Drainage basin is a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or body of impounded surface water together with all tributary surface stream and bodies of impounded surface water.

Gaging station is a particular site on a stream, canal, lake or reservoir where systematic observations of gage height or discharge are obtained.

Particle size is the diameter, in millimeters (mm), of a sediment grain by either sieve or sedimentation methods. Sedimentation methods (pipet, bottom-withdrawal tube, visual-accumulation tube) determine fall diameter of particles in chemically dispersed distilled water.

Geometric standard deviation, σ_g, is a statistical parameter describing the spread of a particle-size distribution which, as suggested by the ASCE Task Committee (Vanoni, 1975), is taken as $\sqrt{D_{84}/D_{16}}$, in which D_{84} and D_{16} are the particle sizes for which 84 percent and 16 percent, respectively, by weight of the sediment is finer.

Median diameter, D_{50}, is the particle size for which 50 percent weight of the sediment is finer.

Particle-size (or grain-size) classification used in this report agrees with recommendations made by the American Geophysical Union Subcommittee on Sediment Terminology. The classification is as follows:

Classification	Size (mm)	Method of analysis
Clay	0.00024-0.004	Sedimentation
Silt	0.004-0.062	Sedimentation
Sand	0.062-2.0	Sedimentation or sieve
Gravel	2.0-64.0	Sieve

The particle-size distributions given in this report are not necessarily representative of all particles in transport in the stream. Most of the organic material in the sample is removed and the sample is subjected to mechanical and chemical dispersion before analysis in distilled water.

Sediment is solid material that is derived mostly from disintegrated rocks and is transformed by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

Additional definitions:

Bedload is the sediment that is transported in a stream by rolling, sliding, or skipping along the bed and very close to it. In this report, bedload is considered to consist of particles in transit within 0.3 ft (0.09 m) of the streambed. For convenience, the bedload will be taken as that part of the total load not measured in the suspended sediment sampling procedure.

Bedload discharge (e.g., tonnes/day) is the rate at which sediment, as measured by dry weight per unit time, moves past a section as bedload.

Mean concentration of suspended sediment is the time-weighted concentration passing a stream section during a 24-hour day.

Suspended sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Suspended-sediment concentration is the velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a point approximately 0.3 ft or 0.09 m above the bed) expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/ℓ).

Suspended-sediment discharge (e.g., tonnes/day) is the rate at which dry weight of suspended sediment passes a section of a stream or is the quantity of sediment, as measured by dry weight, that is discharged in a unit time. It is computed by multiplying discharge times concentration times an appropriate conversion factor.

Total-sediment discharge (e.g., tonnes/day) is the sum of suspended-sediment discharge and the bedload discharge. It is the total quantity of sediment, as measured by dry weight, that passes a section in a given time.

Sediment yield is the amount of sediment delivered to some point, by a stream or river, over some period of time, such as annually.

Actual sediment yield is the true sediment yield of a river or stream.

Natural sediment yield is the sediment yield that would have occurred under pristine conditions (i.e., without the effects of man).

Storm flows are flows derived from surface runoff caused by storms. In this report, any mean daily flows which are not considered to be base flows are classified as storm flows.

Surficial bed material is the part (upper 0.1 to 0.2 ft) of the bed material that is sampled by using U.S. Series Bed-Material Samplers.

Suspended fines is that part of the suspended sediment that is composed of silt-and clay-sized particles, and is considered to be equivalent to the wash load.

Suspended sand is the part of the suspended sediment that is composed of sand.

Wash load is that part of the sediment load that is composed of particle sizes not found in appreciable quantities in the stream bed. The wash load will be taken as equivalent to the suspended fines.

C1.6 Availability of Sediment Data

Figure C1-3 shows the 22 USGS sediment gaging stations in the study area. Between the water years 1957 and 1976, the USGS has published* and/or added to its computer file 920 suspended sediment measurements collected at 20 of the 22 stations. And in conjunction with this project, about 40 more measurements have been made at the remaining two stations, 11088000 and 11090700, beginning with the 1976 water year. These records include sediment concentration and size distribution, water discharge and, usually, temperature.

In addition to the instantaneous sediment records mentioned above, the USGS has made several other types of data available. Based on the instantaneous data, they have provided estimates of daily sediment discharge for about 115 station-years and have published 100 bed-material size distributions. Also, for three years on eight stations, they have given monthly estimates of bedload discharge based primarily on the "modified Einstein" technique.

The above-mentioned data have been used extensively for the analyses appearing in this report.

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*In the series Water Resources Data for Southern California (USGS, 1965-1976) or the appropriate Water Supply Paper.

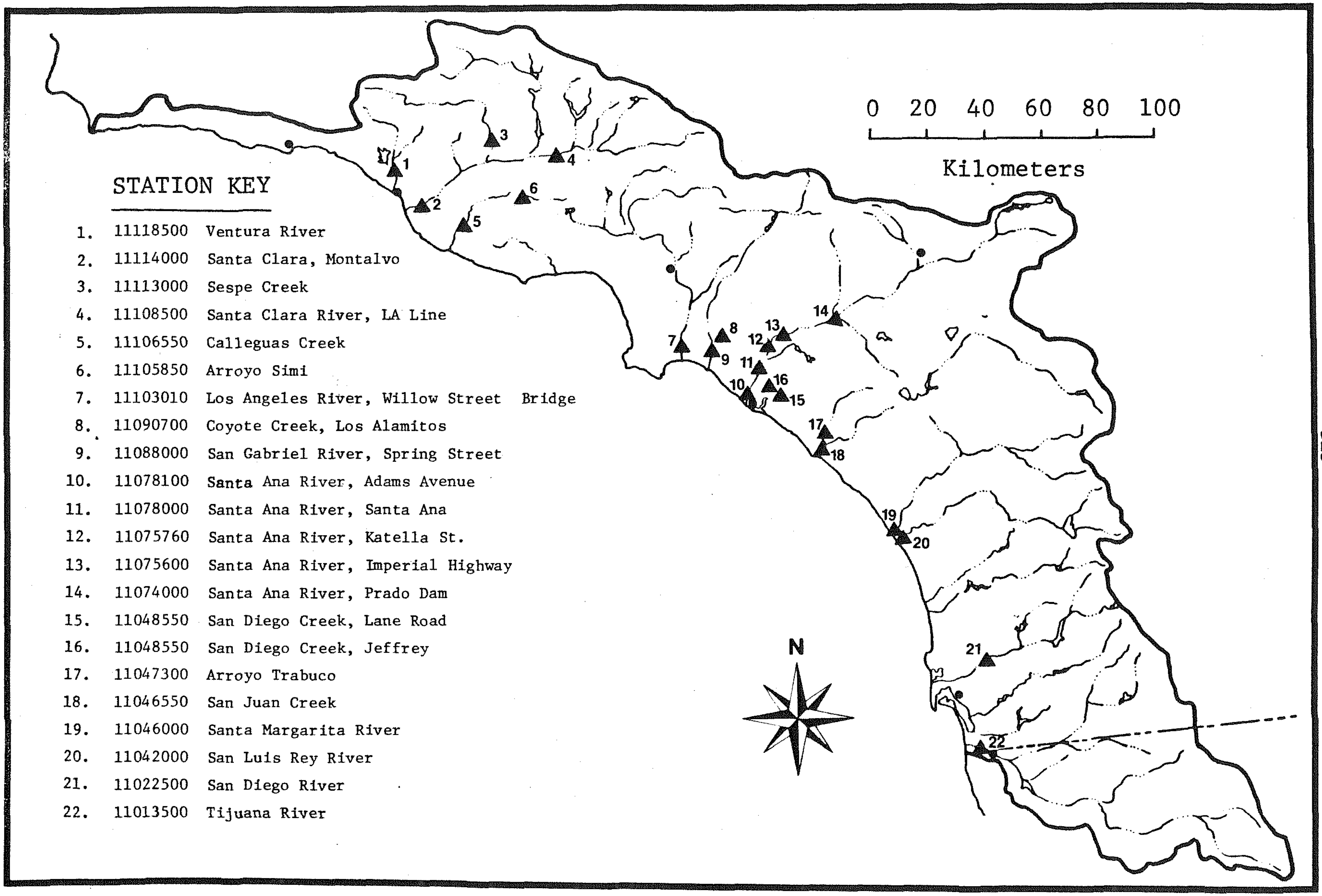

Figure C1-3 Sediment gaging stations in southern California.

C1.7 Predicting Sediment Transport

The total sediment load of a stream can be considered as the sum of the wash load and the bed-material load. The wash load is composed of the finer particles which are not found in appreciable quantities in the bed. The characteristic differences between wash load and bed-material load logically lead to two different approaches to the prediction of sediment transport. When bed-material load is important, at a given instant the load is considered to be in equilibrium with the bed -- the channel and flow characteristics can be studied. However, when wash load is important -- it is not equilibrium with the bed -- it may make more sense to study the sources of the sediment, i.e., the drainage basin.

The method of predicting sediment transport in the moderately developed basins of southern California, though approximate, is consistent with both the drainage basin and the channel approaches.

According to the drainage basin approach, the amount of wash load is a function of a precipitation event and the properties of the basin. If, for a given basin, the following conditions hold:

1. Base flow or groundwater-supplied flow is small or can be accounted for;

2. Precipitation events follow similar geographic and temporal distribution patterns from year to year; for example, in southern California, yearly precipitation is strongly related to elevation; and

3. The basin does not undergo drastic land use changes over the time period of interest;

then the wash load sediment discharge, Q_{sw}, should follow an approximate relationship of the form:

$$Q_{sw} = f(Q) \tag{C1-1}$$

where Q is water discharge, and f(Q) represents an arbitrary function.

Of the three conditions listed above, the most seldom occurring in the study area is the third. However, for the moderately developed basins, it is presumed that these effects are of secondary importance to other man-induced changes of the sediment deliveries. Of the eight basins in this class, probably the San Diego River basin has undergone the greatest land use changes over the past 50 years.

By dimensional analysis, the bed-material discharge should depend on those parameters that independently describe the bed material, the fluid, and flow properties. Then, if the following assumptions are made, an approximate relationship of the form of Eq. C1-1 can also be derived for a particular station, for the bed-material load.

1. The nature of the bed material at the station does not vary greatly with time, so that the bed material parameters can be considered to be approximately constant.

2. Temperature does not vary enough to greatly affect the sediment transport, and therefore, the density and kinematic viscosity of the fluid can be ignored.

3. The energy slope will be approximately equal to the bed slope, which is constant.

4. The wash load concentration need not be included as a separate parameter because Eq. C1-1 gives wash load discharge as a function of Q only.

5. The channel is self-formed and therefore the width, hydraulic radius, mean depth, and mean velocity will approximately be functions of discharge.*

Since all of the parameters are either approximately constant or functions of Q, we should have

$$Q_{sbm} = f(Q) \tag{C1-2}$$

where Q_{sbm} is the bed-material discharge.

Combining Eqs. C1-1 and C1-2 yields the basic relation

$$Q_s = f(Q) \tag{C1-3}$$

where Q_s represents the total sediment discharge. Since the channels of the moderately developed basins are largely self-formed, relationships of the form of Eq. C1-3 will be used extensively. The same cannot be said for the channels of the extensively developed basins.

C1.8 Discussion of Results

More detailed summaries of results are given in sections C12 and C15, for the moderately developed basins and the extensively developed basins, respectively. Only a few general results are presented here.

Figure C1-4 illustrates the degree to which each basin is controlled by major dams. A total of 60 percent of the 23,740 km^2 drainage area is controlled. The degree of control has a great influence on the coastal sediment delivery of all the river systems.

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*This phenomenon has been demonstrated by Leopold and Maddock (1953); however, changing bed forms may cause the functions to be multiple valued.

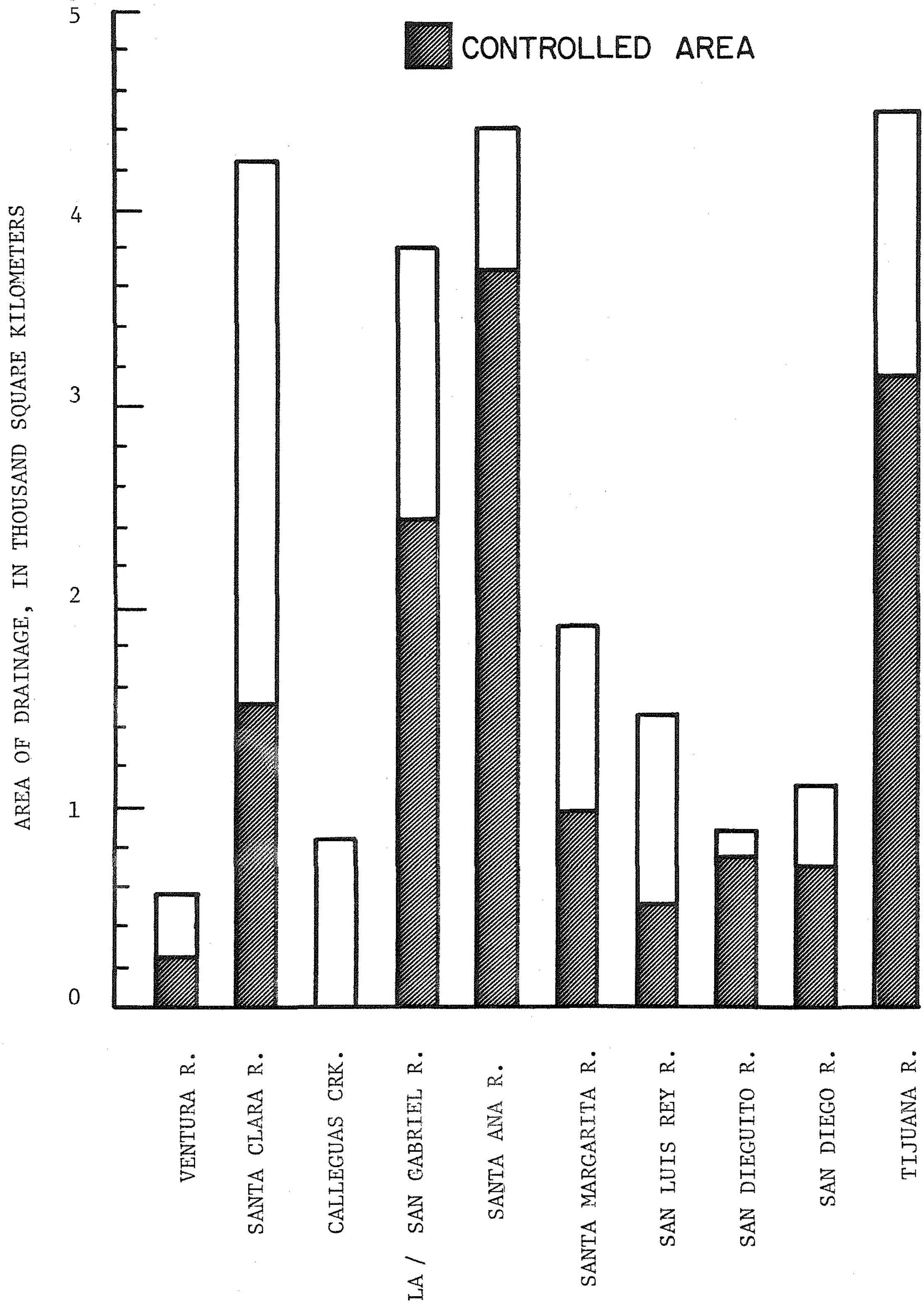

Figure C1-4 Drainage basin areas and degree of control.

The effect of dams on the sediment yields is shown in Fig. C1-5. Dams and diversion structures reduce the flow of water to the ocean, thereby reducing the flow of sediment. Figure C1-5 shows the average annual sand and gravel yields of the major rivers of southern California. The yields for the moderately developed basins represent 25 year averages, with a base period of the water years 1951 through 1975. The yields for the extensively developed basins, i.e., those of the Los Angeles and San Gabriel, and the Santa Ana river basins, represent less precise long-term averages. A comparison of Figs. C1-4 and C1-5 suggests that local features have a significant influence on the sediment yield of a river, beyond its drainage area and degree of control. For example, the small, heavily controlled Ventura River is shown to have a high yield in comparison with many of the southern rivers.

Average annual sediment yields do not tell the whole story. Annual yields can vary significantly from year to year. Figure C1-6 shows a 45 year record of the annual suspended sediment yield of the Santa Clara River. Almost 55 percent of the total actual suspended-sediment yield for the period shown was produced in two water years, 1941 and 1969. If the water years 1944 through 1968 had been selected as the 25 year base period for Fig. C1-5, the actual average annual sand and gravel yield of the Santa Clara River would have been given as 0.350 million tonnes, as compared to 1.15 million tonnes.

The problem of selecting a satisfactory temporal base for comparison of yields is partly responsible for the low values for the southern rivers, as illustrated in Fig. C1-5. The years 1951 through 1975 were selected primarily because they represent a recent period of maximum control. For the southern rivers, these years represent low runoff years, and may not necessarily represent long term averages. In all cases, data analysis was performed whenever sufficient data was available.

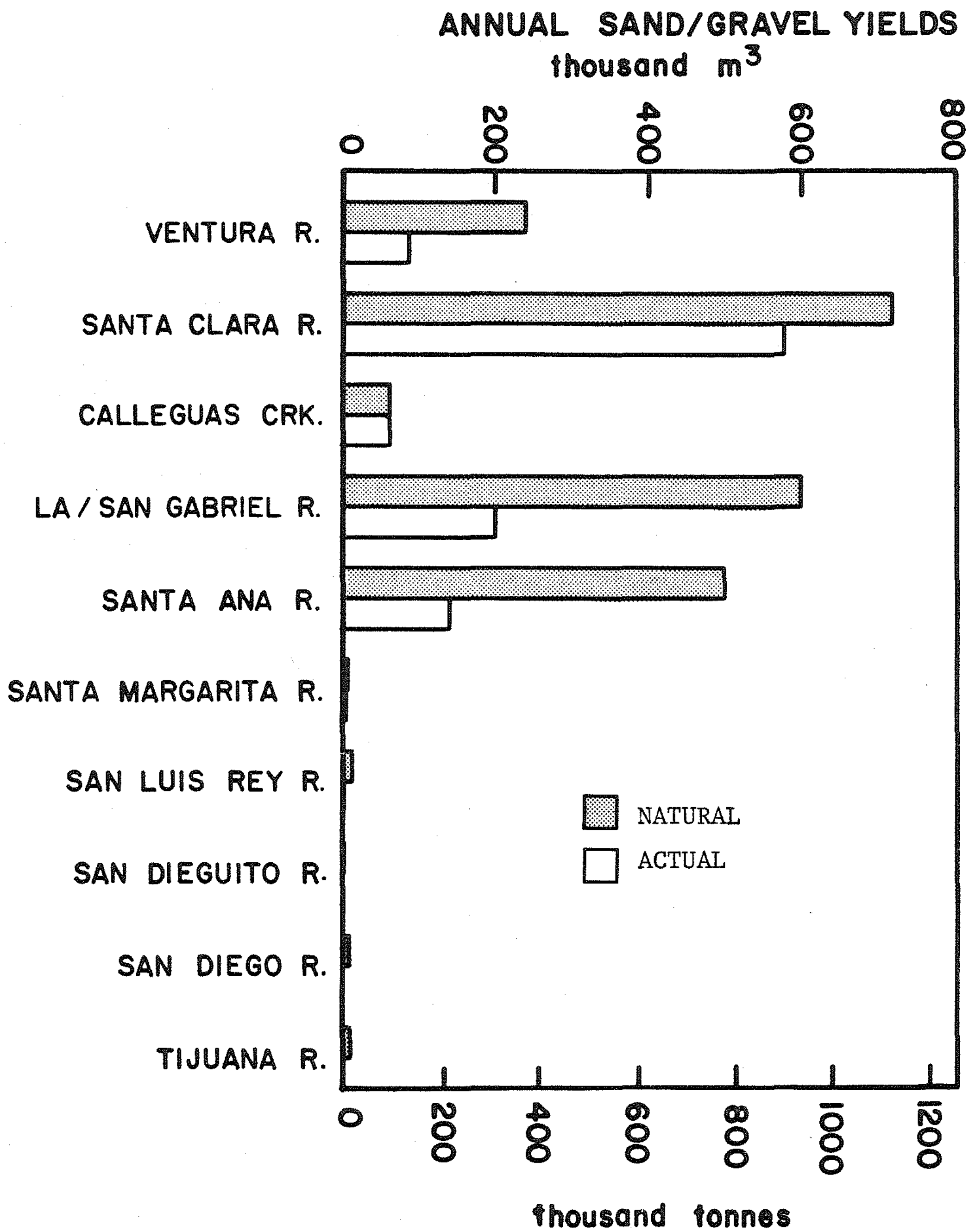

Figure C1-5 Average annual sand and gravel yields for natural conditions.

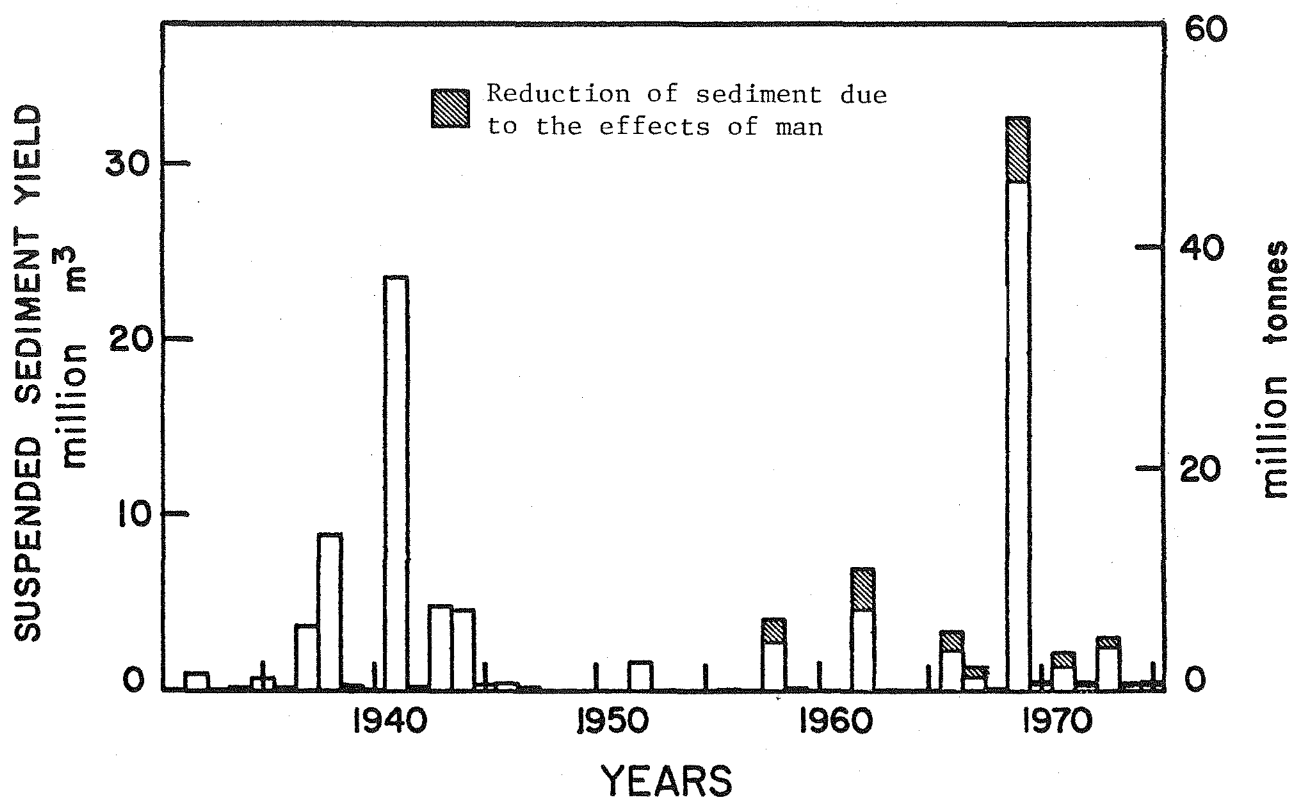

Figure C1-6 Santa Clara River actual annual suspended sediment yields.

MODERATELY DEVELOPED BASINS

By

William R. Brownlie

C2 Moderately Developed Basins - Introduction

In the next eight sections of this report, the eight moderately developed basins are examined in detail. The basins are shown on the map in Fig. C1-1 and listed in Table C1-1. For each of the eight basins estimates of the sediment yields for actual and natural conditions have been determined and are discussed.

For six of the eight basins, the Ventura, Santa Clara, Santa Margarita, San Luis Rey, San Diego, and Tijuana River basins, a common analysis technique has been used. The procedure, based on daily streamflow data, is as follows:

1. For the period of record, each mean daily flow is classified as either a base flow or a storm flow.

2. An instantaneous rating curve is developed from suspended sediment concentration measurements made by the USGS, by linear regression of the logarithms of suspended sediment discharge and water discharge (see section C18.1).

3. The mean daily flow data are then used with the rating curve to estimate actual daily suspended sediment yields for the total period of record. It has been assumed that the continuous flow record can be approximated by a sequence of discrete daily flows without significant error when the results are compiled on an annual basis.

4. By annual summations of daily flows and suspended sediment yields, actual annual storm and base flows and the corresponding annual suspended sediment yields are determined. Where USGS estimates of daily suspended sediment yields are available they are substituted for those determined with the rating curve.

5. An annual sediment rating curve is determined that relates the annual amount of suspended sediment yield that is delivered to the gaging station by storm flows to the annual storm flow (see section C18.2 for a discussion of annual rating curves).

6. Annual natural flows are estimated from a water budget analysis or statistical techniques.

7. By examining daily flow sequences, an assumption is made regarding natural base flows, and the total natural flow is divided into storm flow and base flow.

8. The natural annual suspended sediment yields delivered by storms are determined from the annual rating curve.

9. An assumption is made regarding the natural base flow suspended sediment yield (e.g., on four rivers, the base flows are assumed to be unaltered by the effects of man) and upon combination with the natural storm suspended sediment, the total natural suspended sediment yield is estimated.

10. From published grain size distributions of the suspended load samples an estimate is made for the average annual percent of sand in suspension and an estimate is made for the average annual amount of bed load (if possible). In this way, historic deliveries of both sands and finer material under actual and natural conditions can be estimated.

The two remaining drainage units, the Calleguas Creek and San Dieguito River basins, have limited data bases. No sediment discharge data have been collected on the San Dieguito River for any time period, and no streamflow data were collected on Calleguas Creek prior to October 1968. Consequently, methods involving annual data have been used to make rough estimates of sediment yield for these basins.

In each of the next eight sections of this report, a different drainage basin is discussed. The first of these discussions, pertaining to the Ventura River, contains more general information than do subsequent discussions. The reader is referred to section C3.9 for a brief discussion of the difficulties involved in sampling suspended sand concentrations, as compared with suspended fines.

Since this appendix is also intended to act as a reference for future work, additional information has been provided for each river basin, for example, about geology, extent and availability of streamflow data, and stream bed characteristics. In section C11, this information is compared with respect to the sediment discharge characteristics of the various rivers, and some conclusions are reached.

C3 Ventura River Basin

C3.1 Drainage Basin Description

The Ventura River basin is the northernmost and smallest of the eight drainage basins, with an area of only 585 km^2. The basin is sparsely populated, with a fairly uniform vegetal cover consisting primarily of chaparral, except in the highest areas where there are extensive rock outcroppings. Only 8 percent of the land is used for agricultural purposes, and 11 percent is urbanized. Annual precipitation ranges from 40 cm in the area near sea level to more than 80 cm in the mountain areas above 1500 m elevation. A map of the basin is shown in Fig. C3-1.

C3.2 Geologic Setting

The Ventura River basin lies within the Transverse Ranges province of southern California. The major structural features within this province, such as faults and fold axes, trend in an east-west direction and determine the structural grain of the province.

The Ventura River basin is composed of Cenozoic sedimentary rocks. The stratigraphic section proceeds from older Eocene rocks in the north to younger Plio-Pleistocene rocks in the south as follows: the Eocene marine rocks of well-consolidated shale, sandstone, conglomerate, and minor limestone are overlain by Oligocene nonmarine of mostly well consolidated sandstone, shale, and conglomerate. The Oligocene rocks are in turn overlain by Pliocene marine sandstone, siltstone, shale, and conglomerate, loosely consolidated, and Plio-Pleistocene nonmarine sandstone, shale, and gravel, loosely consolidated. The central part of the basin is a lowland plain filled with Quaternary alluvium, which is the youngest of any deposits in the area.

The Santa Ynez fault is the largest fault within the basin. The fault transects the northern rim of the basin. It trends

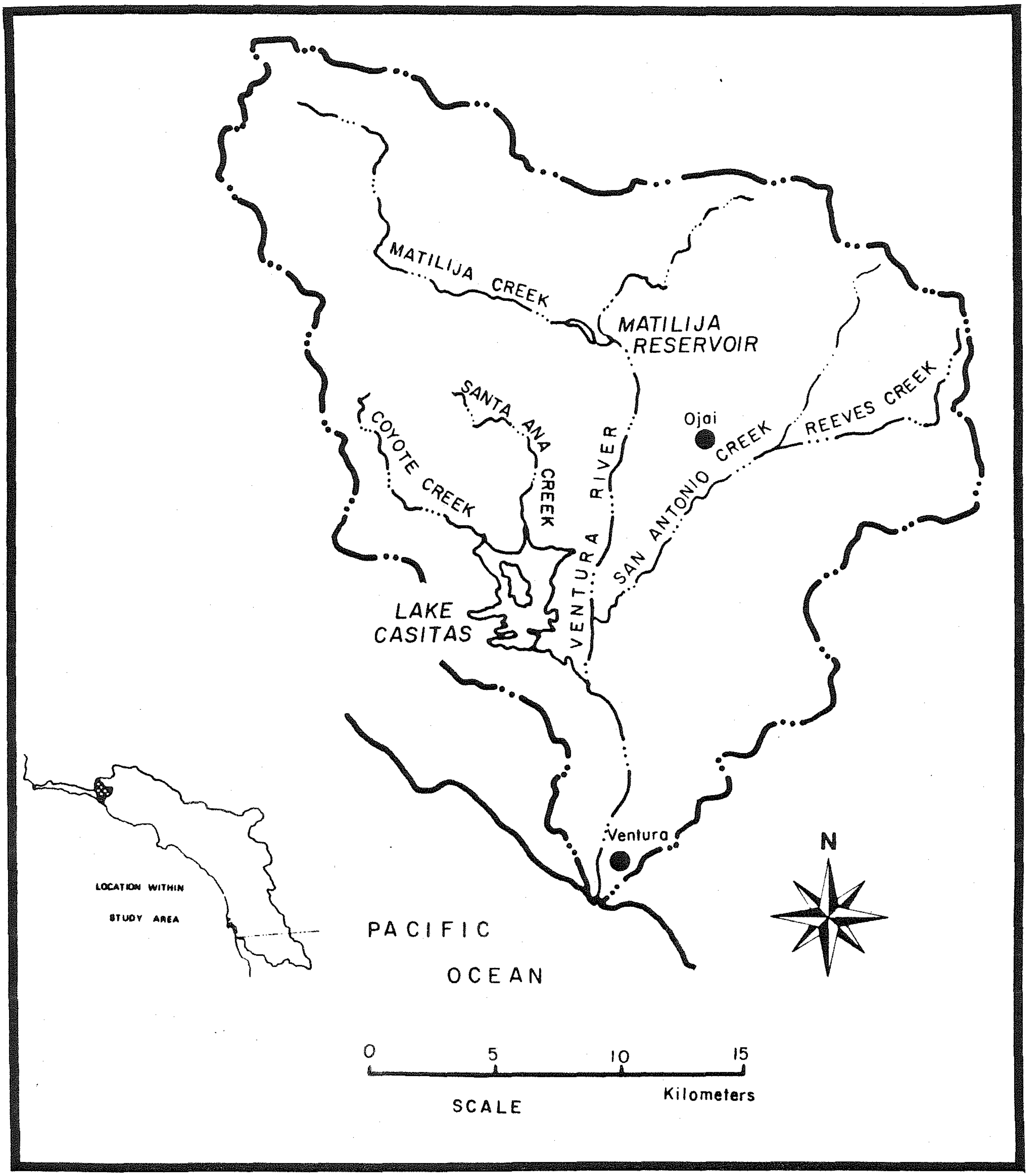

Figure C3-1 Ventura River basin.

east-west, parallel to the surrounding structural grain and juxtaposes different parts of the Eocene and marine section along its length. Other smaller faults are common in both the Eocene and Oligocene sections, but are less abundant in Pliocene and younger rocks.

Folding is extremely common throughout the basin. The fact that no Quaternary deposits show signs of flexure indicates that it occurred prior to Pleistocene time.

C3.3 Control Facilities

There are two major impoundment facilities on the Ventura River basin, Matilija Reservoir and Lake Casitas. Some specifications for the two water-supply facilities are given in Table C3-1. Lake Casitas in October 1959, has had a major effect on the sediment yield of the Ventura River. Flow to the ocean is also affected by the Ventura city diversion.

Matilija Reservoir

Matilija Dam is a small, variable radius concrete-arch dam located on Matilija Creek. The dam, which was completed in March 1948, affects runoff from 24 percent of the total drainage area of the Ventura River basin. The dam is owned and operated by the Ventura County Flood Control District (VCFCD). Water is diverted through pipelines to the Ventura River basin and Ojai Valley for irrigation or is released down the natural channel of Matilija Creek. Since May 1959, flows up to 14.2 m^3/s have been occasionally diverted at Robles diversion dam (at station 11116550, N, Fig. C3-2) to Lake Casitas.

Lake Casitas

Casitas Dam (completed in October 1959) was constructed by the Bureau of Reclamations and is operated by the Casitas Municipal Water District. Water is supplied by direct runoff from Coyote

Table C3-1

Control Structures of the Ventura River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
Matilija Reservoir	2.93	March 1948	142
Lake Casitas	329	October 1959	101

Diversion Facility	Completion Date	Diversion From/To
Ventura City Diversion	Prior to 1911	Water is diverted at station 11118500 for municipal use by City of Ventura, since January 1959 water is stored in Lake Casitas.
Robles Diversion Dam	May 1959	Releases from Matilija Reservoir are diverted near Meiners Oaks, CA (station 11116550) to Lake Casitas

NOTE: Total drainage area of Ventura River basin is 585 km^2.

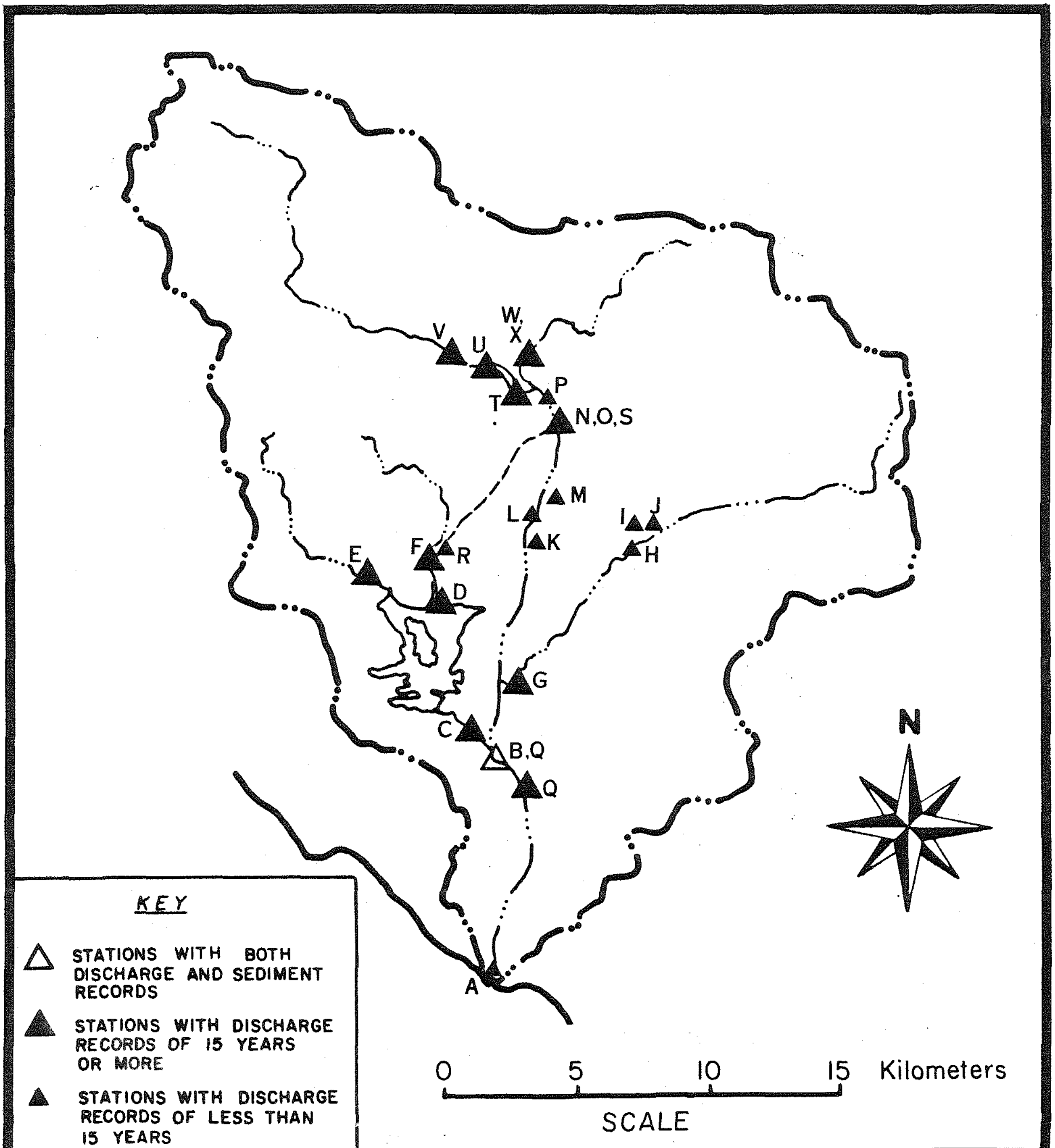

Figure C3-2 Location of streamflow and sediment gaging stations within Ventura River basin.

Table C3-2
Gaging Stations within the Ventura River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG'-MIN'-SEC"	LONGITUDE DEG'-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	3R	Z1-1010		VENTURA R A VENTURA	34-16-54	119-18-30	VEN	8090	SD	1967			F	590.		L
B*	1	Z1-1100	11-1185.00	VENTURA R NR VENTURA	34-21-08	119-18-27	VEN	5000	SD	1911		15	G	487.	63	F
C*	1	Z1-1165	11-1180.00	COYOTE C NR VENTURA	34-21-26	119-18-46	VEN	5000	SD	1927-1958		11	G	107.	69	F
D*	7	Z1-1175	11-1179.00	CASITAS RES A CASITAS DM	34-22-00	119-20-00	VEN	8019	SD	1959			E	287.		L
E*	1	Z1-1230	11-1176.00	COYOTE C NR OAK VIEW	34-25-02	119-22-01	VEN	5000	SD	1958			G	34.2	171	F
F*	1	Z1-1300	11-1178.00	SANTA ANA C NR OAK VIEW	34-25-25	119-20-25	VEN	5000	SD	1958			G	23.6	187	F
G*	1	Z1-1380	11-1175.00	SAN ANTONIO C A CASITAS SPRINGS	34-22-49	119-18-13	VEN	8090	SD	1949			G	133.	93	F
H	1	Z1-1450	11-1170.00	SAN ANTONIO C NR OJAI	34-25-36	119-15-24	VEN	5050	SD	1927-1932			G	87.3		F
I	1	Z1-1460		STEWART CYN	34-26-42	119-14-36	VEN	8090	SD	1968			F	6.22		L
J	3R	Z1-1465		FOX ST DRAIN	34-26-48	119-14-24	VEN	8090	SD	1968			F	3.37		L
K	3R	Z1-1520		SKYLINE DR	34-25-06	119-17-36	VEN	8090	SD	1968			F	2.85		L
L	1	Z1-1535	11-1166.00	VENTURA R A HWY 150 NR OAK VIEW	34-25-30	119-18-06	VEN	8090	SD	1959-1963			G	209.		L
M	3R	Z1-1545		MCDONALD D	34-26-54	119-17-12	VEN	8090	SD	1968			F	3.63		L
N*	1	Z1-1555	11-1165.50	VENTURA R NR MEINERS OAKS	34-27-45	119-17-20	VEN	5000	SD	1959			G	198.	229	F
O	1X	Z1-1600		VENTURA R AB ROBLES DIV DAM	34-28-06	119-17-18	VEN	8019	SD	1960-1969		3	E	198.		L
P	6	Z1-1700	11-1165.00	VENTURA R NR OJAI	34-29-00	119-17-54	VEN	5000	SD	1911-1924		8	G	183.		F
Q*	1	Z1-1925	11-1184.00	VENTURA R DIV NR VENTURA	34-21-00	119-18-24	VEN	5000	SD	1931			G			L
R	1X	Z1-1990		ROBLES-CASITAS CA AT CASITAS RES	34-25-06	119-20-18	VEN	8019	SD	1965			E	199.		L
S*	1	Z1-1995		ROBLES-CASITAS CA NR MEINERS OAKS	34-27-54	119-17-24	VEN	8019	SD	1959			E	198.		L
T*	1	Z1-5150	11-1155.00	MATILIJA C A MATILIJA HOT SPRING	34-28-58	119-18-03	VEN	5000	SD	1927			G	141.	274	F
U*	7	Z1-5320	11-1150.00	MATILIJA RES A MATILIJA HOT SPR	34-29-08	119-18-25	VEN	5000	SD	1948			G	141.		F
V*	1	Z1-5500	11-1145.00	MATILIJA C AB RES NR MATI HOT SPS	34-29-42	119-19-48	VEN	5000	SD	1948-1969			G	131.		F
W*	5	Z1-5930	11-1151.00	MATILIJA C DIV A MATILIJA HOT SPR	34-29-00	119-18-30	VEN	8090	SD	1951			G	141.		F
X*	1	Z1-6150	11-1160.00	MATILIJA C,NF,A MATILIJA HOT SPR	34-29-33	119-18-20	VEN	5121	SD	1928			G	40.2	348	F

*Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

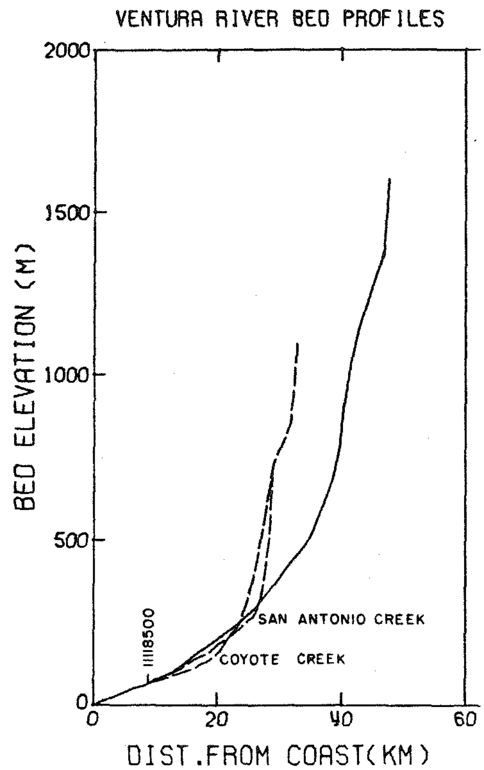

Figure C3-3 Bed profile of main Ventura River channel (solid line) and two tributaries (dashed lines).

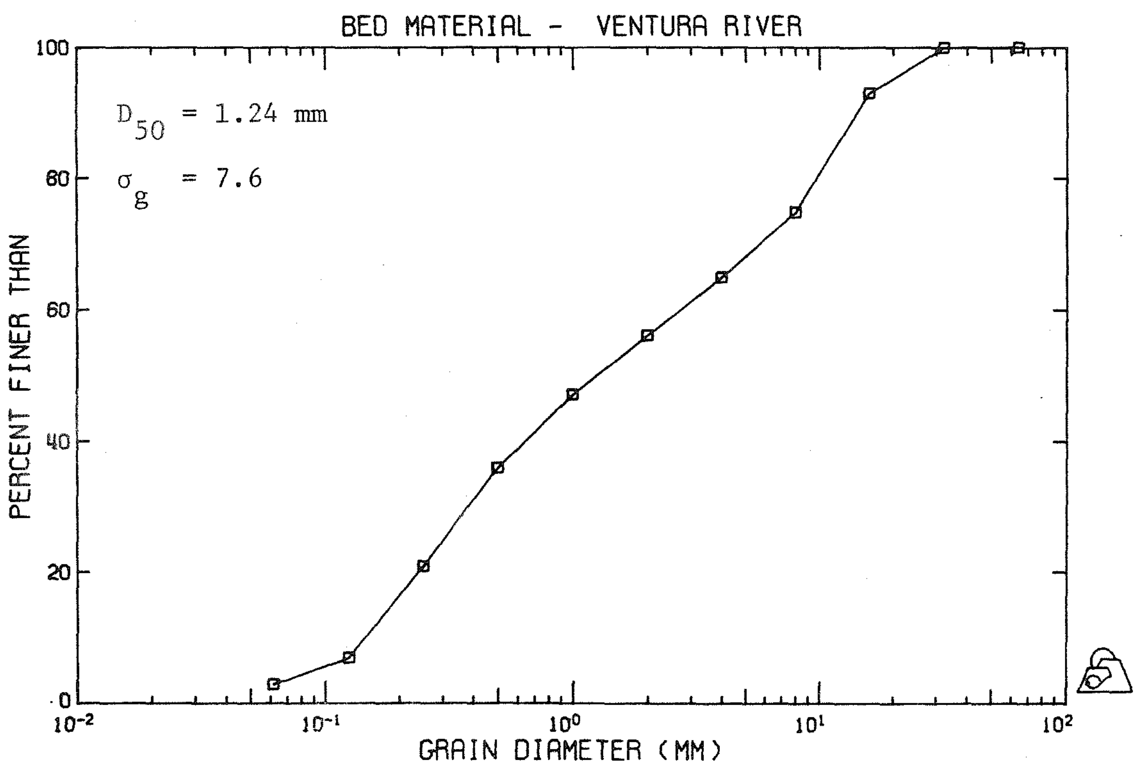

Figure C3-4 Composite bed-material sample collected at station 11118500, September 18, 1973.

Creek, diversions from Matilija Creek at the Robles diversion dam, and from the Ventura River through the Ventura city division. Water from Lake Casitas is supplied* by pipeline for multiple uses including municipal use by the cities of Ventura and Ojai, irrigation, and drilling lubrication by several oil companies.

Ventura City Diversion

Diversions from the Ventura River for municipal use by the City of Ventura began prior to 1911. Since January 1959, diverted water has been stored in Lake Casitas. The diversion is located at the USGS station 11118500 (B, Fig. C3-2). Records of river flow and combined records of river and diversion since October 1932 (1933 water year) are available.**

C3.4 Gaging Stations

Gaging station locations on the basin are shown in Fig. C3-2 and listed in Table C3-2. The stations have been tabulated and illustrated according to record length (15 years or more, or less than 15 years). The map indicates twenty-four stations, of which fourteen have records of 15 years or more.

C3.5 Stream Bed Characteristics

In Fig. C3-3, the bed elevation of the Ventura River is plotted as a solid line against distance from the coast. The figure also shows the bed elevations of the two major tributaries, Coyote Creek and San Antonio Creek, as dashed lines. The channel is extremely steep in comparison with the other seven basins with limited development, with a 1600 m elevation change in about 48 km.

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*Dwight Moore, VCFCD, personal communication, February 12, 1979.

**Records of river flow only available for September 1911 to January 1914, and October 1929 to current year.

The sediment gaging station (11118500) on the Ventura River, as indicated on Fig. C3-3, is 9 km upstream from the river mouth. The bed slope at the gaging station is 7.17 m/km. The bed material at the station was sampled September 18, 1973, by the USGS. The composite sample has a median grain diameter of 1.24 mm with a geometric standard deviation of 7.6. The distribution curve is shown in Fig. C3-4.

The sediment gaging station is located upstream from the mouth and it represents only 83 percent of the total drainage area of the basin. Figure C3-5, a map of the lower reach of the river, indicates that the river flows through a very narrow flood plain downstream of the station. The map also shows that there are some orchards and a small residential area in the lower valley.

The sediment calculations that follow represent transport past the gaging station rather than at the mouth. However, because there is limited development in the lower reach, and percolation and other losses will tend to counteract local inflows, the sediment deliveries at the gaging station probably do not differ greatly from those entering the small lagoon at the mouth.

C3.6 Sediment Rating Curves

Actual suspended sediment deliveries for the water years 1930 through 1968 were estimated from daily streamflow data with the use of an instantaneous sediment rating curve. It was not necessary to apply the technique to water years 1969 through 1976, since the USGS has published estimates of daily suspended sediment for these years. The rating curve was constructed from published USGS suspended sediment concentration data, collected between January 19, 1969, and February 1, 1976. The resulting curve, shown in Fig. C3-6, was fitted by the technique described in Section C18.1. Of the fifty published measurements, one was eliminated because it was considered that the discharge was too

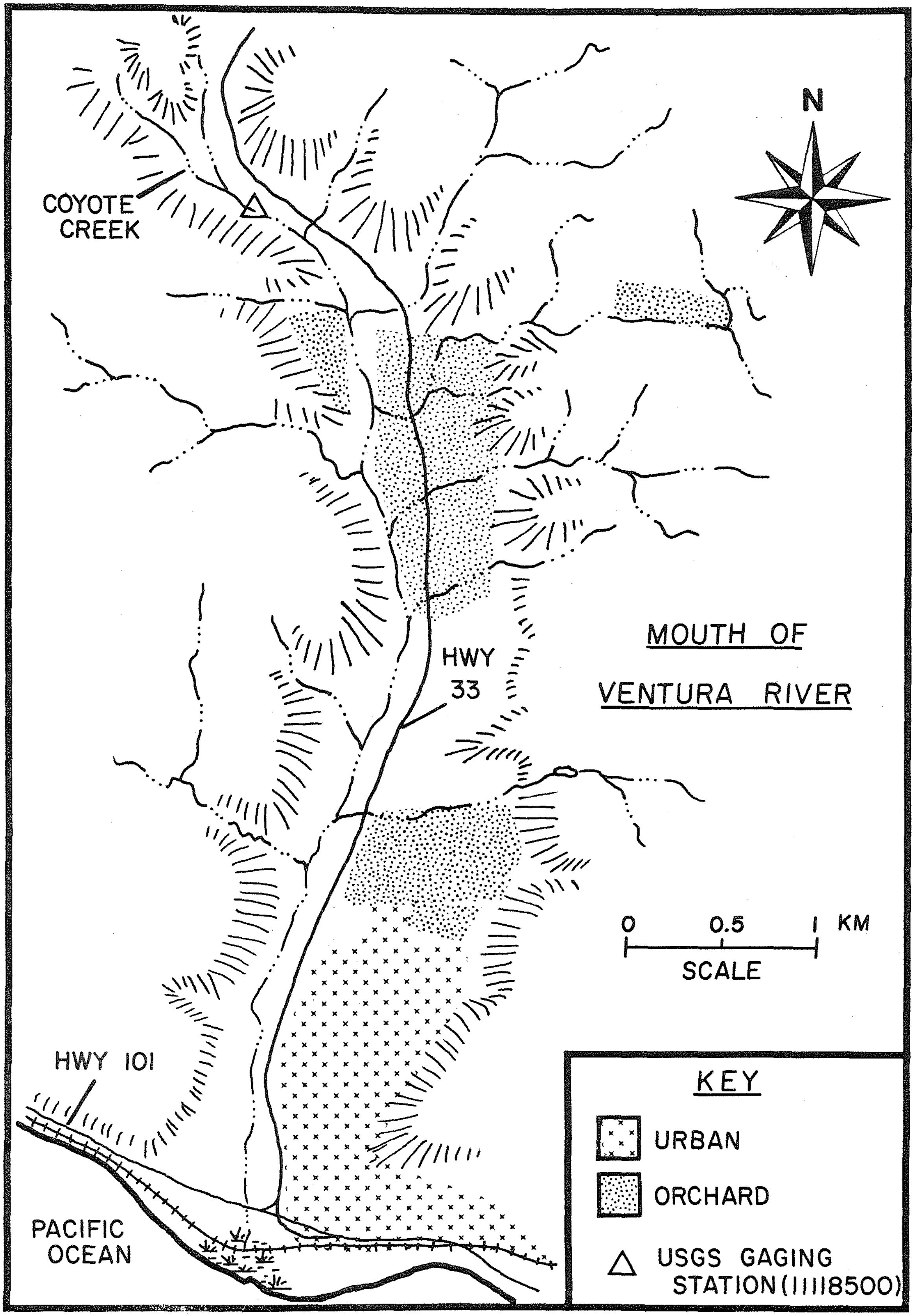

Figure C3-5 Lower reach of Ventura River.

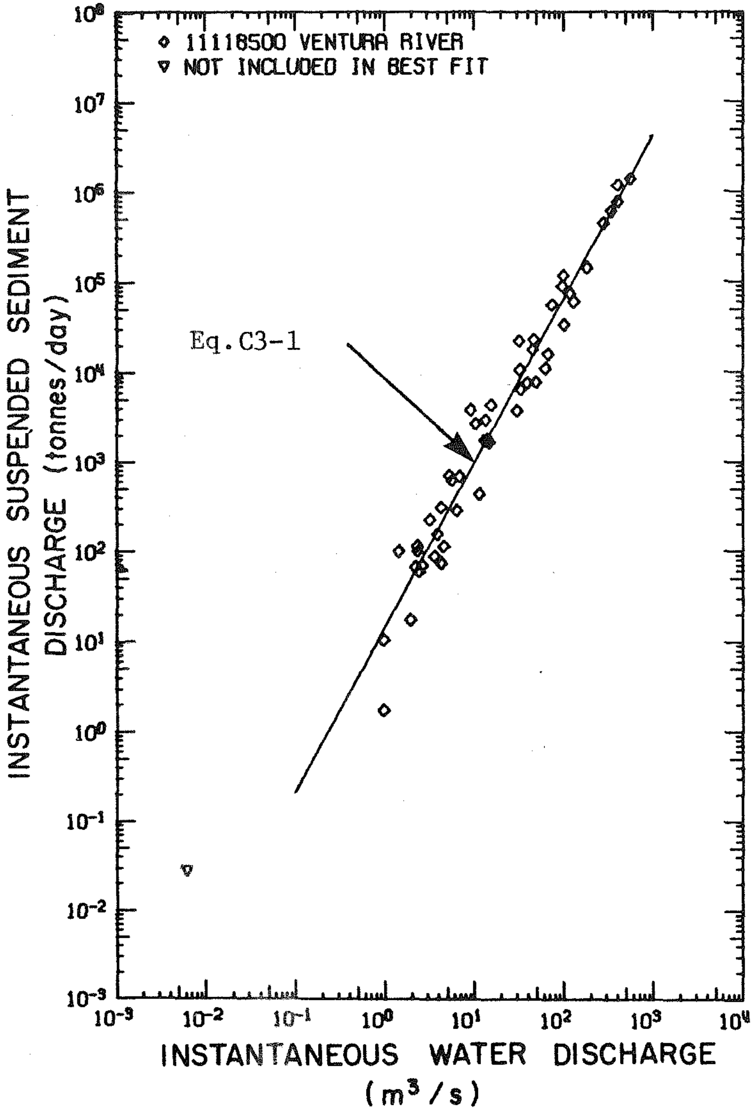

Figure C3-6 Relation of instantaneous sediment discharge to water discharge at Ventura River station 11118500, 1969-76.

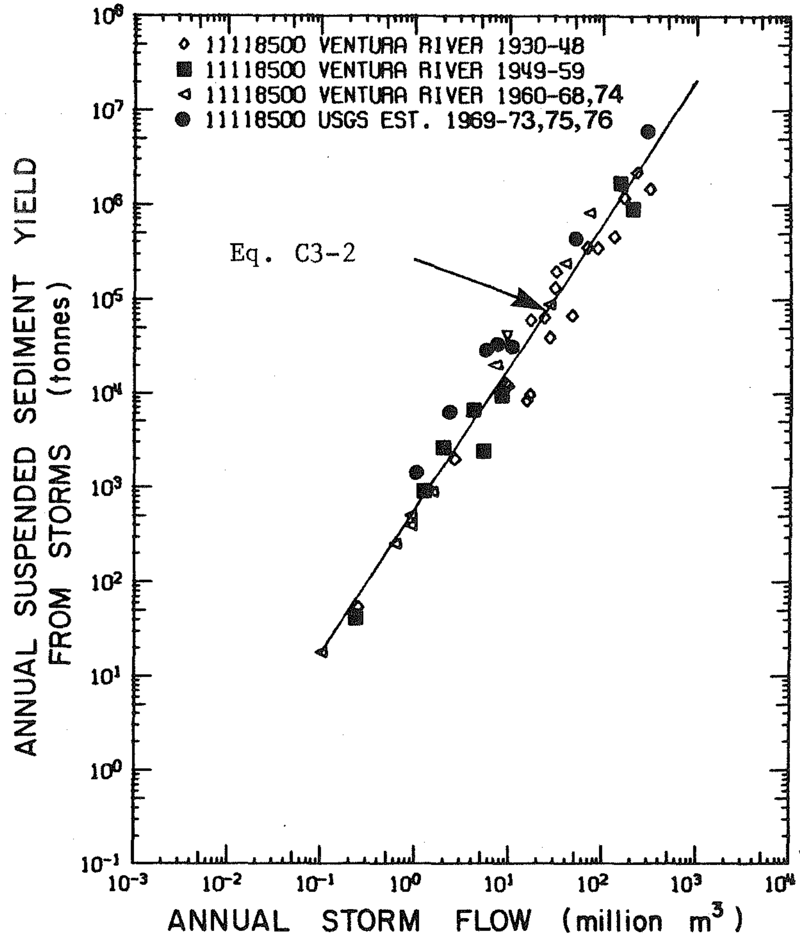

Figure C3-7 Relation of annual suspended sediment delivered by storms to annual storm flow at Ventura River station 11118500, 1930-76.

small to be of importance in the context of this study. The equation for the curve is

$$\hat{Q}_{ss} = 14.2\ Q^{1.83} \qquad \text{(C3-1)}$$

where $\hat{Q}_{ss}$ is the predicted transport rate in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of $\hat{Q}_{ss}$ and Q is 0.978.

To determine the sediment yield that would have occurred under natural uncontrolled conditions, a relationship (Fig. C3-7) between annual suspended sediment yield and annual streamflow was needed. To improve the relationship, base flows were removed and only annual storm flow quantities were correlated. From inspection of streamflow records, it was decided that mean daily flows less than 1 m^3/s would be considered to be base flows, and all other flows would be considered to be storm flows. (A typical annual runoff sequence is shown in Fig. C3-8). The relationship or annual rating curve is,

$$\hat{\forall}_{ss}\ \text{(storm)} = 588\ [\hat{\forall}\ \text{(storm)}]^{1.52} \qquad \text{(C3-2)}$$

where $\hat{\forall}_{ss}$ (storm) is the predicted annual suspended sediment yield from storms, in tonnes, and $\forall$ (storm) is the annual storm runoff, in millions of m^3. Equation C3-2, illustrated in Fig. C3-7, was determined by the method described in Section C18.2. The points in Fig. C3-7 are plotted in four groups. The first three groups represent annual sediment estimates for 1930 through 1968 for periods of increasing control on the basin. The USGS estimates for 1969 through 1976 comprise the fourth group.

It should be noted that in Fig. C3-7, the USGS estimates all lie above the line defined by Eq. C3-2. One reason is that the 1970, 1972, 1973, and 1975 water years were all dominated by single storm events. It is therefore expected that the sediment

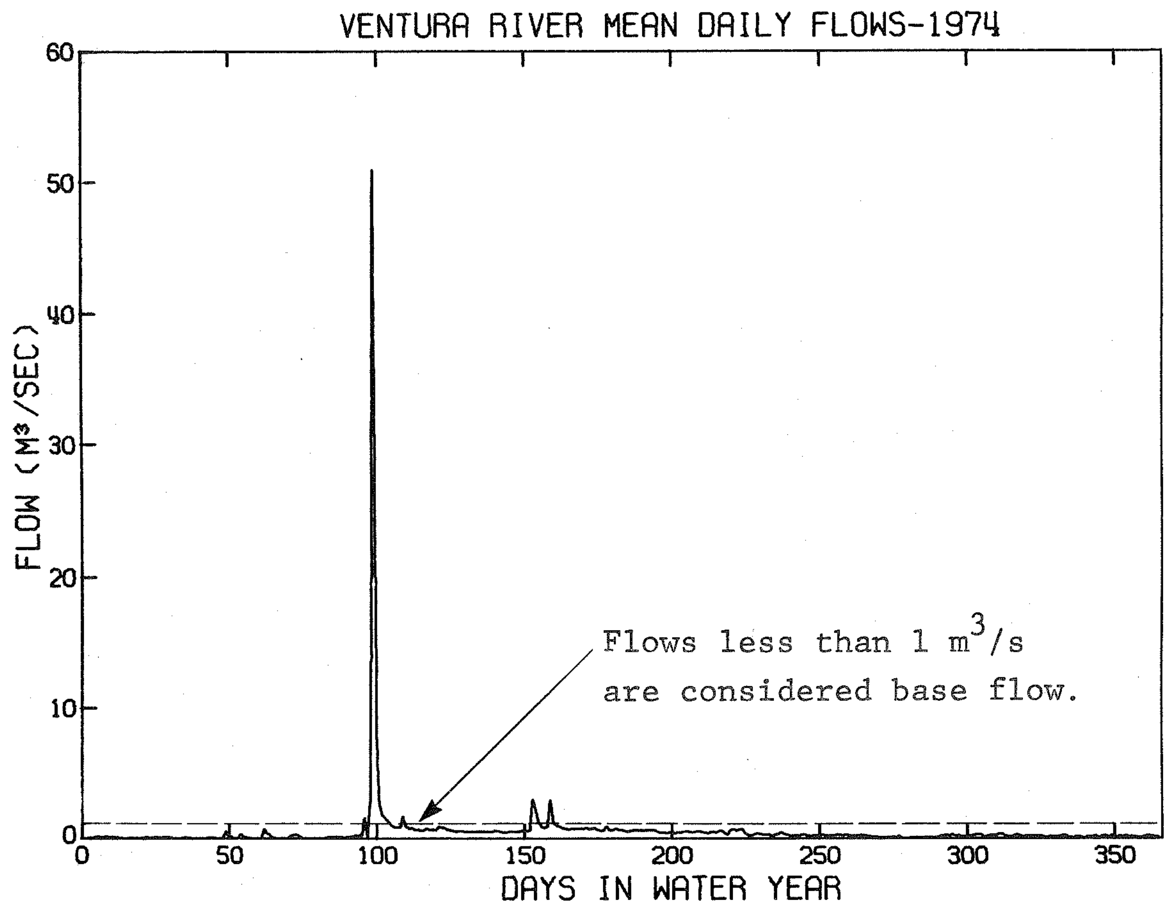

Figure C3-8 Typical annual sequence of mean daily flows (1974 water year) showing chosen cutoff between base flows and storm flows.

yields for these years would be relatively high. A second reason is that the average total suspended sediment yield (for water years 1969-1973, and 1975) determined from Eq. C3-1 and daily flows is 19.6 percent lower than from USGS estimates. This suggests that estimates of historical sediment yields might tend to be on the low side. Since the cause of this discrepancy is not apparent, and this pattern is not observed on other rivers where such a comparison is possible (i.e., the Santa Clara, San Diego, and Tijuana rivers), no correction has been made. Furthermore, although the USGS estimates are the best available, it is clear that they are not exact either.

C3.7 Estimation of Natural Flows

Three major factors, the Ventura city diversion, Matilija Reservoir, and Lake Casitas, have caused reductions to the natural flow in the Ventura River. Some description of these facilities is given in Table C3-1. Since the USGS publishes combined flows of the Ventura River and the Ventura city diversion, it is only necessary to estimate the effects of Matilija Reservoir and Lake Casitas.

Rather than perform a water budget analysis on the two reservoirs and estimate percolation and other losses, it was decided to use statistical techniques to determine their effects. The annual combined flow at station 11118500 on the Ventura River was correlated with the annual flow at station 11116000 on the north fork of Matilija Creek (B and X respectively, on Fig. C3-2), for the coincident uncontrolled period 1934 to 1947, inclusive. As shown in Fig. C3-9, the correlation is very good, with correlation coefficient of 0.997. Since the North Fork of Matilija Creek is totally uncontrolled, it is an excellent predictor of natural flows of the Ventura River. This point is illustrated in Fig. C3-10, a double mass plotting of cumulative flow in the Ventura River versus cumulative flow in the North Fork of Matilija

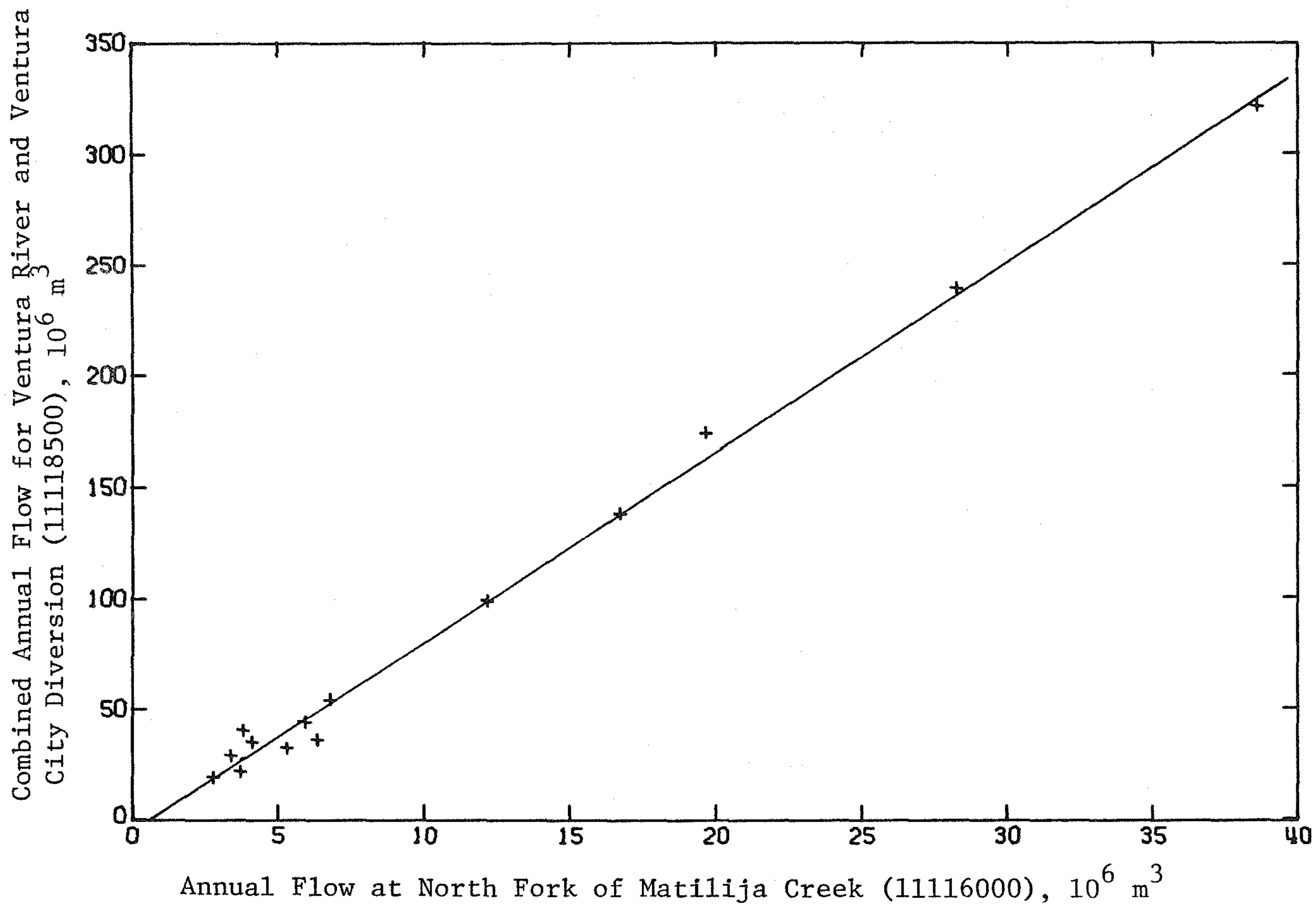

Figure C3-9. Correlation between annual flow for Ventura River plus Ventura city diversion (11118500) and north fork of Matilija Creek (11116000), 1934-1947.

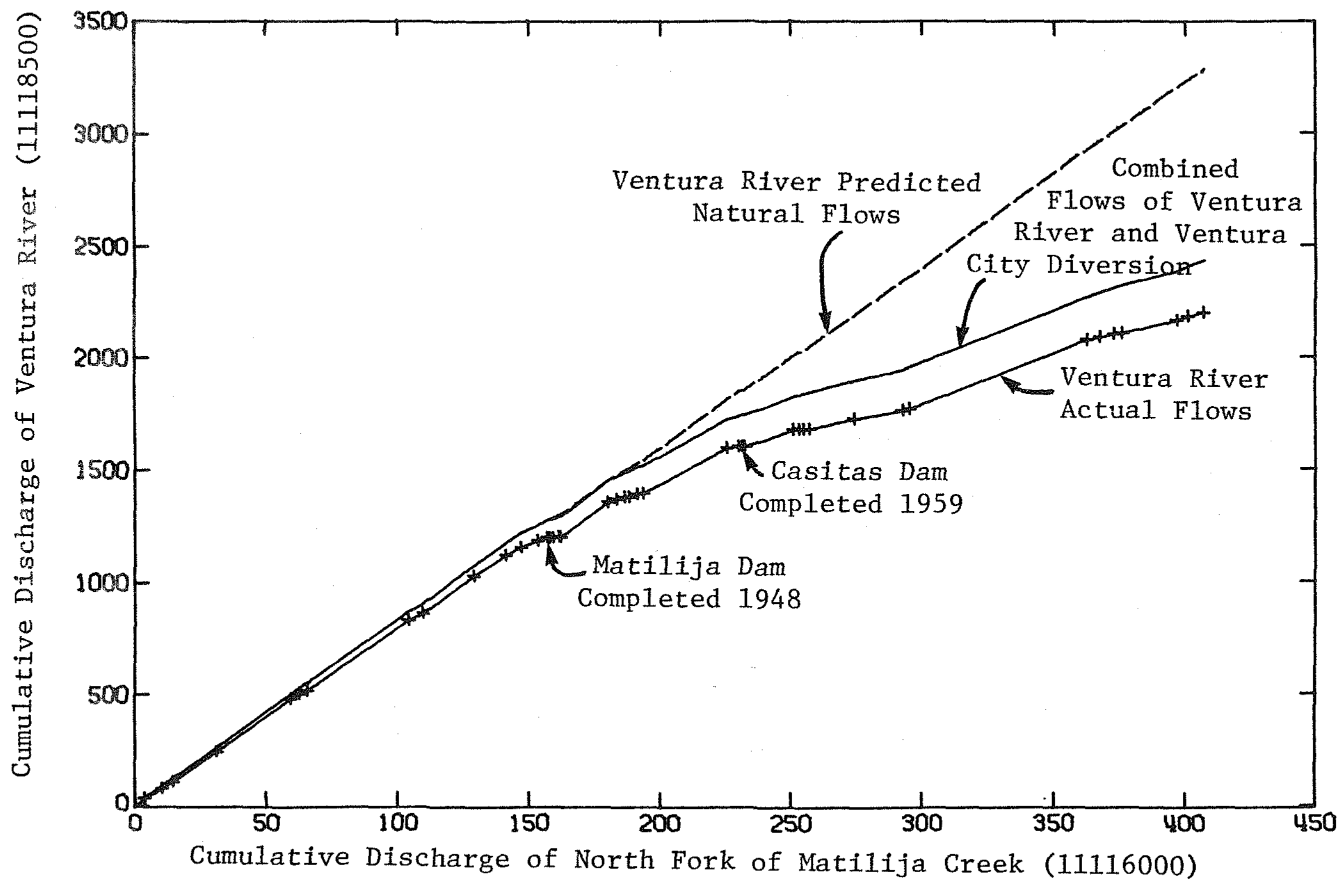

Figure C3-10. Double mass relation between flows of Matilija Creek and the Ventura River for the period 1934-1975. Crosses indicate successive water years, in million m^3.

Creek. The end of each water year is marked with a cross on the lower curve. The dotted line represents natural flows as predicted from flows at the Matilija Creek Station 11116000. Construction of the two dams is indicated by changes in the slopes of the double mass curves of the actual and combined flows.

C3.8 Annual Suspended Sediment Yield

The predicted natural and actual suspended sediment yields are given in Table C3-3. As indicated in the procedural outline in Section C3-2, some assumption is required for the base flow that would have occurred under natural conditions. In this case, it has been assumed that the natural base flow is roughly equivalent to the actual base flow. Some of the natural base flows are diverted by the City of Ventura, so that some error is introduced. However, it is felt that this error is relatively small in comparison with the magnitude of the final results. The cumulative suspended sediment yields are plotted in Fig. C3-11, and listed in Table C3-4.

The results indicated that between the years 1933 and 1975, inclusive, 16.6 tonnes* of suspended sediment have been delivered by the Ventura River. The actual delivery can be compared to 35.2 tonnes of suspended sediment that would have been delivered under natural uncontrolled conditions. Table C3-5 shows the increased reduction of annual sediment deliveries with time and increasing degree of control. For example, the most recent period, 1960 through 1975, has seen a 69 percent decrease in the natural suspended sediment delivery of the river. The table also shows the dominance of the 1969 water year, during which the actual suspended sediment delivery was 15 times that of the mean for the total period 1933 through 1975.

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*One (metric) tonne equals 1000 kg.

Table C3-3
Ventura River (11118500) Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)					ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)				
	1	2	3	1+2	1+3	4	5	6	4+5	4+6
WATER YEAR **	BASE FLOW	STORM ACT FLOW	STORM NAT FLOW*	TOTAL ACT FLOW	TOTAL NAT FLOW *	BASEFLOW SEDIMENT	STORM ACT SED	STORM NAT SED *	TOTAL ACT SED	TOTAL NAT SED*
1930 D	0.91	2.58	-1.00	3.49	-1.00	62.22	1983.24	-1.00	2045.46	-1.00
1931 C	0.09	0.24	-1.00	0.34	-1.00	2.32	54.25	-1.00	56.56	-1.00
1932 D	4.64	66.32	-1.00	70.96	-1.00	410.19	349284.00	-1.00	349694.19	-1.00
1933 D	2.97	16.50	20.79	19.47	23.76	284.47	60690.89	86173.75	60975.36	86458.19
1934 D	4.46	30.73	35.58	35.19	40.04	554.06	194905.94	243408.75	195460.00	243962.81
1935 D	3.73	45.72	50.42	49.45	54.15	396.44	67564.81	78382.88	67961.25	78779.31
1936 D	3.70	26.31	31.36	30.01	35.06	356.55	39471.06	51528.72	39827.61	51885.27
1937 D	4.20	129.15	134.19	133.35	138.40	384.94	452631.19	479746.50	453016.13	480131.44
1938 D	7.65	226.89	231.65	234.54	239.30	748.00	2187390.00	2257412.00	2188138.00	2258160.00
1939 D	7.15	16.24	21.67	23.39	28.82	667.99	9638.65	14935.63	10306.64	15603.62
1940 D	4.55	8.95	14.43	13.50	18.98	395.74	12789.64	26421.70	13185.38	26817.45
1941 D	3.50	312.70	317.83	316.20	321.33	444.00	1465186.00	1501827.00	1465630.00	1502271.00
1942 D	12.39	14.99	20.01	27.38	32.40	1504.39	8388.09	12999.27	9892.48	14503.66
1943 D	4.02	164.36	170.07	168.38	174.09	331.00	1184944.00	1247978.00	1185275.00	1248309.00
1944 D	7.06	85.16	91.41	92.22	98.47	660.81	342415.19	381283.06	343076.00	381943.88
1945 D	7.56	29.55	36.22	37.11	43.78	647.81	131468.94	179069.75	132116.75	179717.56
1946 D	5.82	22.97	30.12	28.79	35.95	475.76	64473.88	97307.25	64949.64	97783.00
1947 D	4.58	9.47	16.86	14.05	21.44	357.52	11982.73	28741.03	12340.26	29098.55
1948 D	0.06	0.0	3.10	0.06	3.16	0.20	0.0	3276.39	0.20	3276.59
1949 D	0.20	0.0	7.06	0.20	7.25	18.91	0.0	11412.82	18.91	11431.73
1950 D	1.30	1.98	11.03	3.28	12.33	70.01	2635.87	35636.91	2705.88	35706.91
1951 N	0.0	0.0	1.38	0.0	1.38	0.0	0.0	955.66	0.0	955.66
1952 D	2.59	151.46	145.46	154.06	148.05	197.00	1635694.00	1538303.00	1635891.00	1538500.00
1953 D	5.28	5.13	19.37	10.42	24.66	495.82	2456.32	18441.63	2952.14	18937.45
1954 D	2.64	8.67	19.18	11.31	21.82	186.24	10432.70	34840.28	10618.94	35026.52
1955 D	0.88	0.22	8.47	1.11	9.35	20.51	45.18	11274.70	65.69	11295.21
1956 D	3.12	9.21	18.47	12.33	21.59	183.00	41452.64	119182.19	41635.64	119365.19
1957 D	1.32	1.39	13.20	2.71	14.52	69.64	883.49	26774.88	953.13	26844.51
1958 D	5.24	193.55	261.98	198.79	267.23	509.94	930202.56	1472708.00	930712.50	1473217.00
1959 D	3.21	4.14	31.84	7.36	35.06	124.14	6617.57	146098.44	6741.71	146222.56
1960 D	1.07	0.61	5.09	1.68	6.16	20.32	251.38	6236.39	271.70	6256.71
1961 D	0.16	0.10	1.88	0.26	2.04	2.65	17.85	1575.38	20.50	1578.03
1962 C	3.22	69.68	150.88	72.90	154.10	196.56	821037.44	2652164.00	821234.00	2652360.00
1963 D	2.32	0.89	13.13	3.21	15.45	80.11	506.42	30038.00	586.53	30118.11
1964 D	0.27	0.0	8.28	0.27	8.55	9.27	0.0	14548.45	9.27	14557.71
1965 D	1.33	0.89	13.60	2.22	14.93	69.86	396.54	24653.32	466.41	24723.18
1966 D	6.81	38.47	134.89	45.28	141.70	602.75	241490.31	1621191.00	242093.06	1621793.00
1967 D	8.66	25.83	146.16	34.49	154.82	822.31	88907.88	1233987.00	89730.19	1234809.00
1968 D	5.44	1.51	11.83	6.95	17.27	351.47	905.65	20568.48	1257.13	20919.95
1969 U	5.05	303.43	566.99	308.48	572.04	192.00	6030898.00	15576027.00	6031090.00	15576219.00
1970 U	6.59	5.74	28.73	12.33	35.32	116.80	29609.90	341406.88	29726.70	341523.63
1971 U	6.55	7.41	36.27	13.96	42.82	105.50	33698.90	375271.94	33804.40	375377.44
1972 U	1.35	2.35	20.16	3.70	21.51	31.10	6404.70	167250.63	6435.80	167281.69
1973 U	7.26	50.93	164.09	58.20	171.35	68.69	445579.38	2630605.00	445648.06	2630673.00
1974 U	9.41	7.29	23.40	16.70	32.81	878.43	19986.63	117442.56	20865.06	118320.94
1975 U	6.11	10.40	38.99	16.51	45.10	2999.60	32703.80	242957.13	35703.40	245956.69
1976 U	0.67	1.05	-1.00	1.71	-1.00	15.70	1440.60	-1.00	1456.30	-1.00

*Negative one (-1.00) indicates data unavailable.
**See Table C3-4.

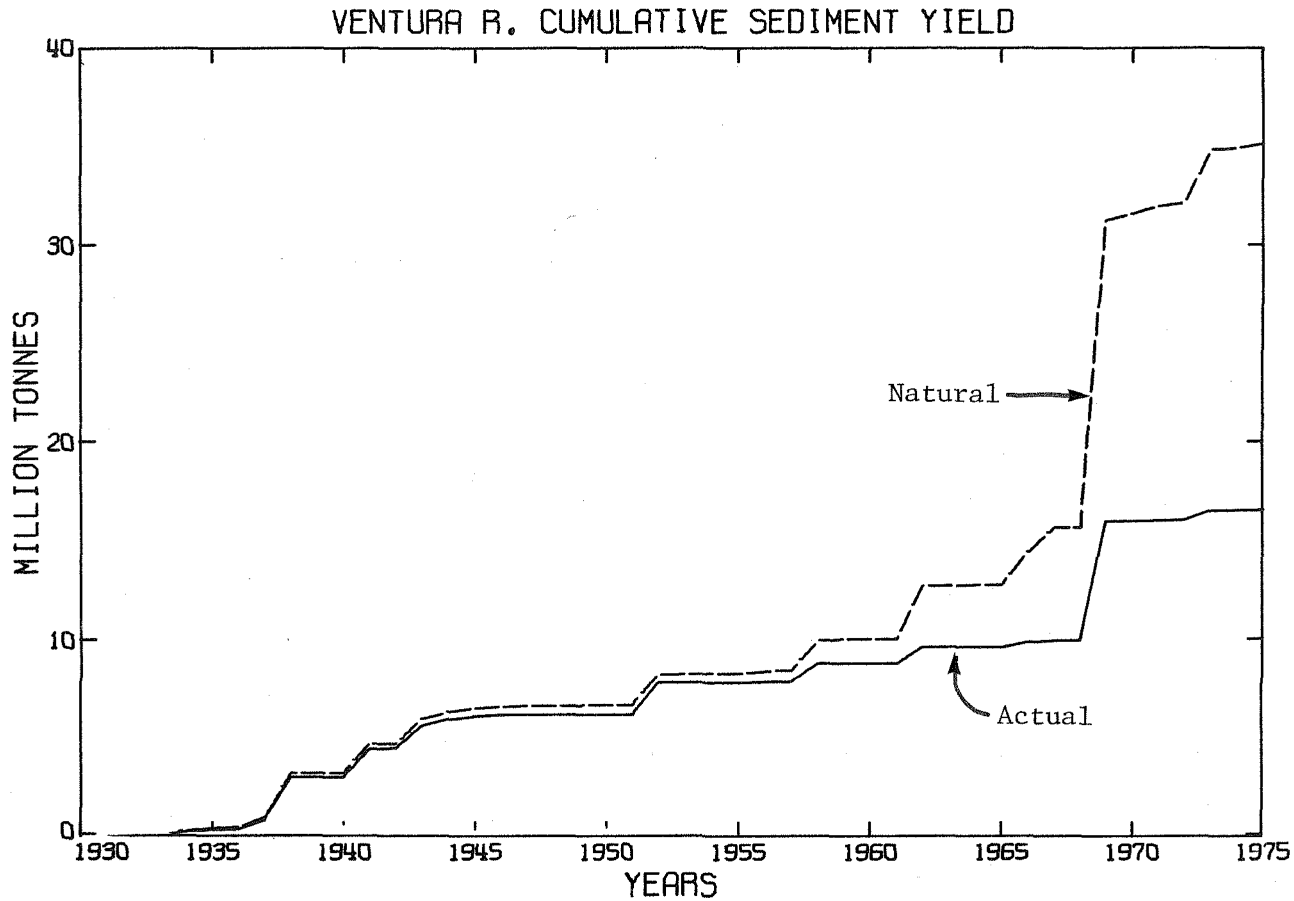

Figure C3-11. Cumulative natural and actual suspended sediment yield at Ventura River station 11118500.

Table C3-4
Ventura River (11118500)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1933 D	0.06	0.09
1934 D	0.26	0.33
1935 D	0.32	0.41
1936 D	0.36	0.46
1937 D	0.82	0.94
1938 D	3.01	3.20
1939 D	3.02	3.21
1940 D	3.03	3.24
1941 D	4.49	4.74
1942 D	4.50	4.76
1943 D	5.69	6.01
1944 D	6.03	6.39
1945 D	6.16	6.57
1946 D	6.23	6.67
1947 D	6.24	6.70
1948 D	6.24	6.70
1949 D	6.24	6.71
1950 D	6.24	6.75
1951 N	6.24	6.75
1952 D	7.88	8.29
1953 D	7.88	8.30
1954 D	7.89	8.34
1955 D	7.89	8.35
1956 D	7.94	8.47
1957 D	7.94	8.50
1958 D	8.87	9.97
1959 D	8.87	10.12
1960 D	8.87	10.12
1961 D	8.87	10.12
1962 D	9.70	12.78
1963 D	9.70	12.81
1964 D	9.70	12.82
1965 D	9.70	12.85
1966 D	9.94	14.47
1967 D	10.03	15.70
1968 D	10.03	15.72
1969 U	16.06	31.30
1970 U	16.09	31.64
1971 U	16.12	32.02
1972 U	16.13	32.18
1973 U	16.58	34.81
1974 D	16.60	34.93
1975 U	16.63	35.18

*Suspended sand plus washload.
**Actual based on: D-Daily Flows, U-USGS Estimates; N-No Flow.

Table C3-5
Average Suspended Sediment Deliveries in Millions of Tonnes per Year by the Ventura River

PERIOD	AVERAGE ANNUAL SUSPENDED SEDIMENT DELIVERY		PERCENT REDUCTION	CONTROL
	Natural	Actual		
1933 - 1948	0.419	0.390	7%	Ventura City Diversion only
1949 - 1959	0.311	0.239	23%	Matilija Reservoir added
1960 - 1975	1.47	0.46	69%	Lake Casitas added
1933 - 1975	0.80	0.38	53%	
1969 only	15.6	6.03	61%	

C3.9 Annual Sand in Suspension

The suspended load is composed of a sand fraction, which is assumed to be in equilibrium with the bed, and a fine (silt and clay) fraction, the wash load, which is not in equilibrium with the bed. The wash load concentration for a given discharge will vary between storms due to variations in precipitation characteristics over the drainage basin. However, at a particular site, the wash load concentration will be fairly uniform over the cross section, and will vary slowly over short time periods. On the other hand, the coarse part of the load will vary greatly over the cross section both horizontally and vertically. Vertical variation is due to the concentration profile that results from the balance of upward turbulent diffusion of particles and particle settling. Horizontal variation is due to local variations of the bed elevation, bed form, and bed material. The amount of sand in suspension varies, on a short time scale, with turbulent fluctuations in the flow, or bursts of turbulence.

As a consequence of the different characteristics of the two transport fractions, the sand fraction of depth-integrated samples, such as those collected by the USGS, is more susceptible to experimental error. In general, for the southern California data, more relative scatter is evident in the sand fraction data alone than in the total suspended load data. However, for the Ventura and Santa Clara rivers and Calleguas Creek, the data are sufficient to make a reasonable judgement about the suspended sand yield. For the other rivers, the data are too sparse and scattered, and only rough estimates can be made.

Instantaneous suspended sand transport is plotted as a function of water discharge in Fig. C3-12. The data samples are the same as those plotted in Fig. C3-6, except that only the fraction of coarser than 0.062 mm is plotted. Equation C3-1, represented by the dashed line on Fig. C3-12, is the best fit equation for total suspended load. A curve made up of

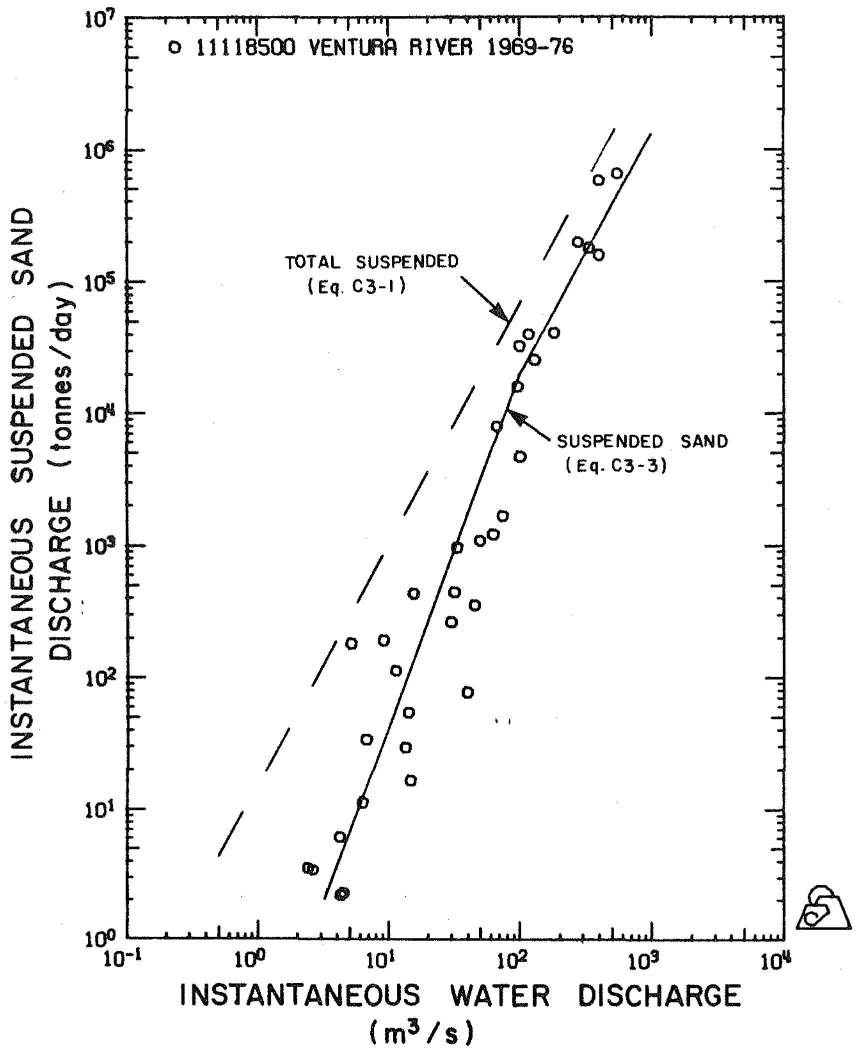

Figure C3-12 Relation of instantaneous suspended sand discharge to water discharge at Ventura River station 11118500, 1969-76.

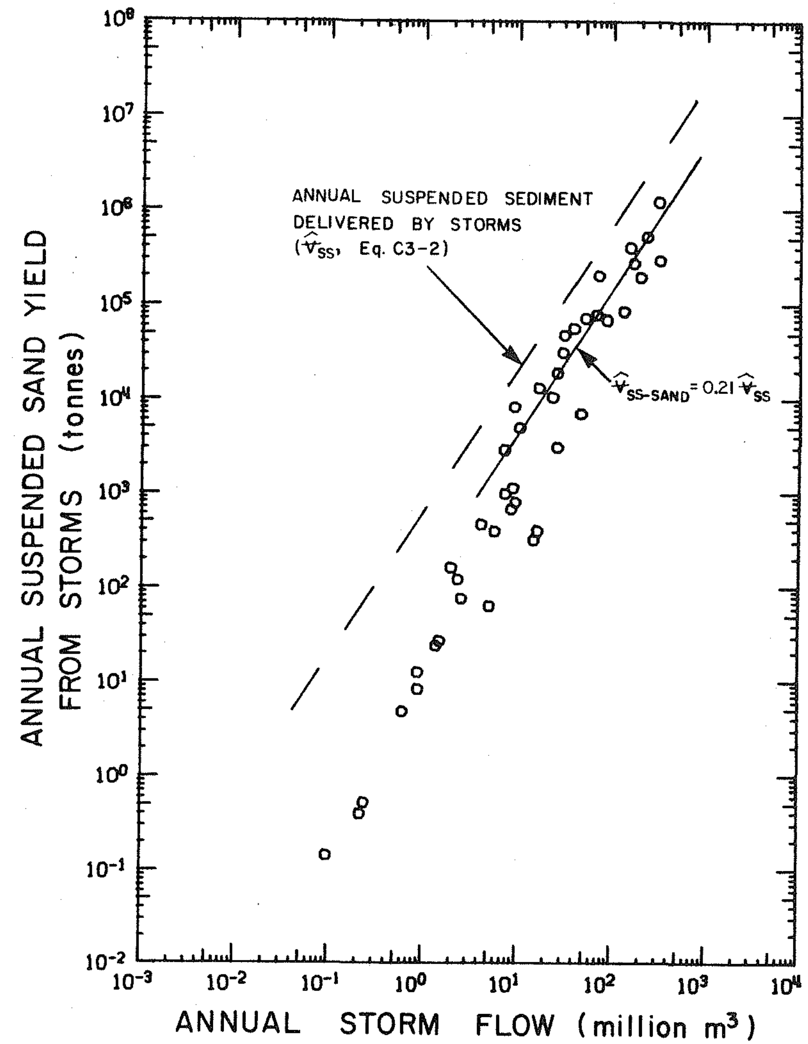

Figure C3-13 Relation of annual suspended sand yield produced by storms to annual storm flow at Ventura River station 11118500, 1930-76.

two straight line segments for the log-log plot was fitted to the suspended sand data. For discharges (Q) greater than 100 m^3/s, the equation is

$$\hat{Q}_{ss-sand} = 3.64\ Q^{1.83},\ \text{for } Q > 100\ m^3/s \qquad \text{(C3-3a)}$$

where $\hat{Q}_{ss-sand}$ is the predicted suspended sand transport rate in tonnes/day. The exponent in Eq. C3-3a was set equal to the exponent of Eq. C3-1, and the coefficient was determined from Eq. C18-7b of section C18.1. For discharges less than or equal to 100 m^3/s, the equation

$$\hat{Q}_{ss-sand} = 0.103\ Q^{2.6},\ \text{for } Q \leq 100\ m^3/s \qquad \text{(C3-3b)}$$

was fitted by eye. The curve fitting was done in such a way that Eq. C3-3 would never predict a greater value than Eq. C3-1.

Using Eq. C3-3 with daily streamflow values gives an estimate of suspended sand production. Figure C3-13 shows the predicted annual suspended sand yield produced by storms as a function of annual storm flow. The dashed line represents Eq. C3-2 which predicts the total annual suspended sediment produced by storms. The solid line on Fig. C3-13 illustrates that, for annual storm runoffs greater than 50 million m^3, the annual suspended sand yield approaches a constant fraction of the total suspended sediment yield (about 21%). This point is further illustrated in Tables C3-6 and C3-7. Table C3-6 gives annual suspended sediment yield and suspended sand yield (including base flows), and tha ratio of the two, as percent sand. Table C3-7 presents the same data on a cumulative basis. In this case, for a given year, the percent sand column represents the cumulative suspended sand delivery for the period 1930 to the given year. From these estimates, we can deduce that after only a few years, the cumulative percent sand in suspension fluctuated only slightly from year to year (between 21 and 23%).

Table C3-6
Ventura River (11118500) Actual Total Sediment Yields, in Tonnes

	1	2	3	4	5	6	7	8	9
	2+3			3/1		5/1	5/3	3+5	1+5
WATER YEAR	SUSP. YIELD, SY	SUSP. FINES	SUSP. SAND, SS	PERCENT SAND	BEDLOAD YIELD, BL	BL/SY (%)	BL/SS (%)	SAND AND COARSER	TOTAL YIELD
1930	2045.46	1968.25	77.21	3.77	362.75	17.73	469.82	439.97	2408.21
1931	56.56	56.03	0.53	0.94	11.04	19.51	2086.20	11.56	67.60
1932	349694.19	271099.75	78594.44	22.48	53345.46	15.25	67.87	131939.88	403039.63
1933	60975.36	47763.54	13211.82	21.67	9511.76	15.60	71.99	22723.59	70487.13
1934	195460.00	147425.00	48034.95	24.58	29682.10	15.19	61.79	77717.00	225142.06
1935	67961.25	60948.61	7012.64	10.32	11267.31	16.58	160.67	18279.95	79228.50
1936	39827.61	36756.65	3070.95	7.71	6696.09	16.81	218.05	9767.04	46523.70
1937	453016.13	367555.06	85461.06	18.86	70608.38	15.59	82.62	156069.44	523624.50
1938	2188138.00	1668195.00	519942.75	23.76	317240.31	14.50	61.01	837183.06	2505378.00
1939	10306.64	9908.23	398.40	3.87	1847.48	17.93	463.72	2245.89	12154.12
1940	13185.38	12049.71	1135.66	8.61	2214.55	16.80	195.00	3350.21	15399.93
1941	1465630.00	1172017.00	293612.88	20.03	225828.38	15.41	76.91	519441.25	1691458.00
1942	9892.48	9565.79	326.69	3.30	1800.16	18.20	551.03	2126.85	11692.64
1943	1185275.00	912067.38	273207.63	23.05	175786.19	14.83	64.34	448993.81	1361061.00
1944	343076.00	273635.81	69440.19	20.24	52580.78	15.33	75.72	122020.94	395656.75
1945	132116.75	100727.81	31388.88	23.76	20093.40	15.21	64.01	51482.29	152210.13
1946	64949.64	54327.56	10622.09	16.35	10363.95	15.96	97.57	20986.04	75313.56
1947	12340.26	11538.03	802.23	6.50	2107.18	17.08	262.67	2909.40	14447.43
1948	0.20	0.20	0.00	0.00	0.05	25.50	510000.75	0.05	0.25
1949	18.91	18.80	0.11	0.61	3.82	20.22	3326.09	3.94	22.74
1950	2705.88	2541.47	164.41	6.08	462.43	17.09	281.27	626.84	3168.31
1951	0.00	0.0	0.00	100.00	0.0	0.0	0.0	0.0	0.0
1952	1635891.00	1234944.00	400946.56	24.51	236363.88	14.45	58.95	637310.44	1872254.00
1953	2952.14	2885.18	66.96	2.27	548.39	18.58	819.03	615.35	3500.53
1954	10618.94	9942.64	676.30	6.37	1813.68	17.08	268.18	2489.98	12432.61
1955	65.69	65.24	0.45	0.68	13.32	20.28	2973.88	13.77	79.01
1956	41635.64	33337.75	8297.89	19.93	6500.57	15.61	78.34	14798.47	48136.22
1957	953.13	928.62	24.51	2.57	173.63	18.22	708.30	198.14	1126.75
1958	930712.50	736252.68	194459.63	20.89	143322.75	15.40	73.70	337782.38	1074035.00
1959	6741.71	6276.58	465.13	6.90	1141.39	16.93	245.39	1606.52	7883.09
1960	271.70	266.84	4.86	1.79	51.12	18.82	1051.68	55.98	322.82
1961	20.50	20.36	0.15	0.72	4.11	20.05	2796.60	4.26	24.61
1962	821234.00	619452.94	201781.06	24.57	119852.75	14.59	59.40	321633.81	941086.75
1963	586.53	573.60	12.93	2.20	109.19	18.62	844.57	122.12	695.73
1964	9.27	9.23	0.04	0.43	1.94	20.98	4860.00	1.98	11.21
1965	466.41	457.74	8.67	1.86	87.63	18.79	1011.10	96.30	554.04
1966	242093.06	185386.38	56706.65	23.42	36854.89	15.22	64.99	93561.50	278947.94
1967	89730.19	70664.94	19065.20	21.25	14050.91	15.66	73.70	33116.11	103781.06
1968	1257.13	1228.26	28.87	2.30	236.27	18.79	818.47	265.13	1493.39
1969	6031090.00	4804245.00	1226845.00	20.34	697552.19	11.57	56.86	1924397.00	6728642.00
1970	29726.70	29333.02	393.67	1.32	1290.66	4.34	327.85	1684.33	31017.35
1971	33804.40	32821.84	982.56	2.91	2269.79	6.71	231.01	3252.35	36074.18
1972	6435.80	6312.82	122.98	1.91	435.34	6.76	353.99	558.32	6871.14
1973	445648.06	373733.06	71915.00	16.14	48546.37	10.89	67.51	120461.31	494194.38
1974	20865.06	17995.91	2869.15	13.75	3380.36	16.20	117.82	6249.52	24245.42
1975	35703.40	30755.21	4948.18	13.86	5230.16	14.65	105.70	10178.34	40933.56

Table C3-7
Ventura River (11118500) Cumulative Actual Total Sediment Yields, in 10^6 Tonnes

	1	2	3	4	5	6	7	8	9
	2+3			3/1		5/1	5/3	3+5	1+5
WATER YEAR	SUSP. YIELD,SY	SUSP. FINES	SUSP. SAND,SS	PERCENT SAND	BEDLOAD YIELD,BL	BL/SY (%)	BL/SS (%)	SAND AND COARSER	TOTAL YIELD
1930	0.00	0.00	0.00	3.77	0.00	17.73	469.82	0.00	0.00
1931	0.00	0.00	0.00	3.70	0.00	17.78	480.82	0.00	0.00
1932	0.35	0.27	0.08	22.36	0.05	15.27	68.28	0.13	0.41
1933	0.41	0.32	0.09	22.26	0.06	15.32	68.82	0.16	0.48
1934	0.61	0.47	0.14	23.00	0.09	15.28	66.40	0.23	0.70
1935	0.68	0.53	0.15	21.73	0.10	15.41	70.90	0.25	0.78
1936	0.72	0.57	0.15	20.95	0.11	15.49	73.92	0.26	0.83
1937	1.17	0.93	0.24	20.14	0.18	15.52	77.08	0.42	1.35
1938	3.36	2.60	0.76	22.50	0.50	14.86	66.02	1.25	3.86
1939	3.37	2.61	0.76	22.44	0.50	14.86	66.23	1.26	3.87
1940	3.38	2.62	0.76	22.39	0.50	14.87	66.42	1.26	3.88
1941	4.85	3.80	1.05	21.68	0.73	15.03	69.36	1.78	5.57
1942	4.86	3.81	1.05	21.64	0.73	15.04	69.51	1.78	5.59
1943	6.04	4.72	1.32	21.92	0.91	15.00	68.44	2.23	6.95
1944	6.38	4.99	1.39	21.83	0.96	15.02	68.80	2.35	7.34
1945	6.52	5.09	1.42	21.87	0.98	15.02	68.70	2.40	7.50
1946	6.58	5.15	1.44	21.81	0.99	15.03	68.91	2.42	7.57
1947	6.59	5.16	1.44	21.78	0.99	15.03	69.02	2.43	7.59
1948	6.59	5.16	1.44	21.78	0.99	15.03	69.02	2.43	7.59
1949	6.59	5.16	1.44	21.78	0.99	15.03	69.02	2.43	7.59
1950	6.60	5.16	1.44	21.78	0.99	15.04	69.04	2.43	7.59
1951	6.60	5.16	1.44	21.78	0.99	15.04	69.04	2.43	7.59
1952	8.23	6.40	1.84	22.32	1.23	14.92	66.84	3.07	9.46
1953	8.24	6.40	1.84	22.31	1.23	14.92	66.87	3.07	9.46
1954	8.25	6.41	1.84	22.29	1.23	14.92	66.94	3.07	9.48
1955	8.25	6.41	1.84	22.29	1.23	14.92	66.94	3.07	9.48
1956	8.29	6.44	1.85	22.28	1.24	14.93	66.99	3.08	9.52
1957	8.29	6.44	1.85	22.28	1.24	14.93	67.00	3.08	9.53
1958	9.22	7.18	2.04	22.14	1.38	14.97	67.64	3.42	10.60
1959	9.23	7.18	2.04	22.13	1.38	14.98	67.68	3.42	10.61
1960	9.23	7.19	2.04	22.13	1.38	14.98	67.68	3.42	10.61
1961	9.23	7.19	2.04	22.13	1.38	14.98	67.68	3.42	10.61
1962	10.05	7.80	2.24	22.33	1.50	14.94	66.94	3.74	11.55
1963	10.05	7.81	2.24	22.32	1.50	14.94	66.94	3.74	11.55
1964	10.05	7.81	2.24	22.32	1.50	14.94	66.94	3.74	11.55
1965	10.05	7.81	2.24	22.32	1.50	14.94	66.95	3.75	11.55
1966	10.29	7.99	2.30	22.35	1.54	14.95	66.90	3.84	11.83
1967	10.38	8.06	2.32	22.34	1.55	14.96	66.96	3.87	11.93
1968	10.38	8.06	2.32	22.34	1.55	14.96	66.96	3.87	11.93
1969	16.41	12.87	3.55	21.60	2.25	13.71	63.47	5.80	18.66
1970	16.44	12.90	3.55	21.57	2.25	13.69	63.50	5.80	18.69
1971	16.48	12.93	3.55	21.53	2.25	13.68	63.54	5.80	18.73
1972	16.48	12.94	3.55	21.52	2.25	13.68	63.55	5.80	18.74
1973	16.93	13.31	3.62	21.38	2.30	13.60	63.63	5.92	19.23
1974	16.95	13.33	3.62	21.37	2.31	13.61	63.67	5.93	19.26
1975	16.99	13.36	3.63	21.35	2.31	13.61	63.73	5.94	19.30

C3.10 Bedload Discharge

Bedload discharge is one of the most difficult quantities to deal with in the field of sediment transport. No measurement or computational technique is universally accepted. However, one commonly used method is the "modified Einstein" procedure of Colby and Hembree (1955). The technique estimates the unmeasured bedload discharge (as defined in Section C1) given the suspended load concentration and particle-size distribution, the particle-size distribution of the bed material and the flow depth, surface width and velocity. A computerized version of the procedure (Burkham et al., 1977) is used by the USGS for bedload calculations, and for consistency, has been used here. While the basic technique is widely known, its accuracy under field conditions is still largely unknown.

The computer program was run for a number of events with a wide range of discharges, where sufficient data were available. The results are summarized in Table C3-8. The calculated bedload discharges are plotted as a function of water discharge in Fig. C3-14. A bedload rating curve, fitted to the points by the technique of Section C18.1, is given by

$$\hat{Q}_{sb} = 2.28\ Q^{1.77} \tag{C3-4}$$

where $\hat{Q}_{sb}$ is the predicted bedload discharge in tonnes/day. For the 10 data points, the correlation coefficient between log Q_{sb} and log Q is 0.972. By again using the daily discharge data, annual estimates of bedload yield can be obtained. The annual estimates are given in Table C3-6 and on a cumulative basis in Table C3-7. From Table C3-7, the estimated 46 year average ratio of bedload yield to suspended load yield is 13.6 percent.

C3.11 Summary

The sediment yield calculations for the Ventura River are summarized in Table C3-9. Cumulative actual sediment yields are plotted in Fig. C3-15. For the total period of record (1933-1975), the table shows that the predicted average annual yield of sand and coarser material has been about 0.135 million tonnes. Prior to the major floods of the 1969 water year, Herron and Harris (1967, p. 653) stated that the "average annual supply of littoral material [by the Ventura River] is estimated at about 100,000 cubic yards [76,500 m^3]," based on sedimentation studies of delta deposits. Using a bulk density of 1.6 tonnes/m^3 (100 lb/ft^3), this estimate converts to an average annual yield of 0.122 million tonnes. The predictions are remarkably similar and tend to corroborate the validity of each technique. However, the techniques presented herein have supplied detailed information such as natural sediment yields, which cannot be obtained from sedimentation studies alone.

Another type of comparison can be made between the reduction of natural sediment yield and the accumulation of sediment in Matilija Reservoir. Surveys of the reservoir in 1948 and 1970 indicated that in 22 years the capacity had been reduced by 1.94 million m^3*. Assuming a dry bulk sediment density of 1.04 tonnes/m^3 (65 lb/ft^3), this represents an average annual accumulation of 91,500 tonnes. From Table C3-5, the average annual suspended sediment reduction can be found for the period 1949 through 1959, when Matilija Reservoir was the major cause of sediment reduction. Scaling the suspended sediment reduction by 1.147 to include the bedload yield for the given period gives a total average annual sediment reduction of 82,600 tonnes. These figures agree reasonably well; however, they are not expected to be the same. The reservoir

*Jerry Bickel, Ventura County Flood Control District, personal communication, April 1977.

Table C3-8
Summary of Ventura River Total Sediment Load Calculations

		Observed				Calculated		
			Suspended Sediment Discharge (tonnes/day)					
Date	Time	Q Water Discharge (m^3/sec)	$Q_{ss\text{-}fine}$	$Q_{ss\text{-}sand}$	Q_{ss} Total Susp.	Q_{sb} Bedload Discharge (tonnes/day)	Q_s Total Sediment Discharge (tonnes/day)	$\frac{Q_{sb}}{Q_{ss}}$ (%)
Jan 19, 1969	930	4.30	71.1	2.2	73.3	10.8	84.1	14.7
Jan 26, 1969	1015	402	608,000	562,000	1,170,000	202,000	1,370,000	17.3
Feb 4, 1969	1300	11.4	322	113	435	74.5	510	17.1
Feb 24, 1969	1540	555	745,000	635,000	1,380,000	169,000	1,550,000	12.2
Mar 12, 1969	1430	9.20	3,670	193	3,860	412	4,270	10.7
Mar 1, 1970	1200	28.6	19,500	398	19,900	1,070	21,000	5.4
Dec 21, 1970	1540	17.0	2,100	65.1	2,170	483	2,650	22.2
Dec 28, 1971	1200	1.93	44.6	2.8	47.4	22.4	69.8	47.3
Jan 20, 1973	800	0.906	1.6	---	1.6	0.1	1.7	6
Feb 10, 1973	1600	84.1	63,800	14,000	77,800	7,840	85,600	10.1
Feb 11, 1973	1215	213	118,000	48,000	166,000	26,900	193,000	16.2

Note: All figures are rounded to three digits or to one place to the right of the decimal point.

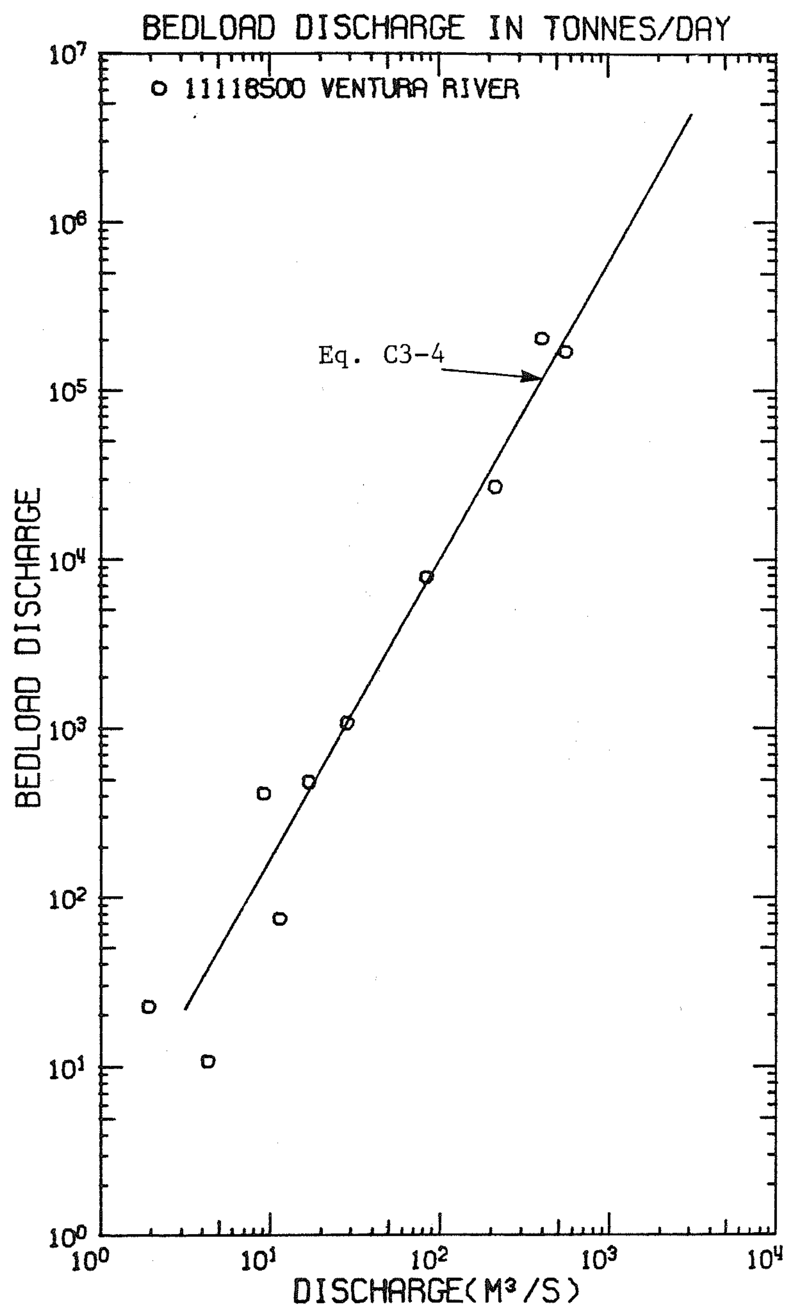

Figure C3-14 Ventura River calculated bedload discharge as a function of water discharge.

Table C3-9
Ventura River Average Annual Sediment Yield

Annual Sediment Yield in Million Tonnes

Mode of Transport and Sediment Size Class	Total Period of Record 1933 - 75		Period of Maximum Control 1960 - 75		Largest Event 1969 Water Year	
	Actual	Natural	Actual	Natural	Actual	Natural
Total Suspended Load	0.387	0.818	0.485	1.57	6.03	15.6
Suspended Fines (wash load)	0.305	0.643	0.386	1.24	4.80	12.4
Suspended Sand	0.0826	0.175	0.0994	0.321	1.23	3.18
Estimated Bedload (sand & gravel)	0.0526	0.111	0.0581	0.188	0.698	1.80
Total Sand and Gravel (bed-material load)	0.135	0.286	0.158	0.510	1.93	4.98
Total Sediment Load	0.439	0.929	0.545	1.76	6.73	17.4
$\frac{\text{Actual Sand Yield}}{\text{Natural Sand Yield}}$ (%)	47%		31%		39%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

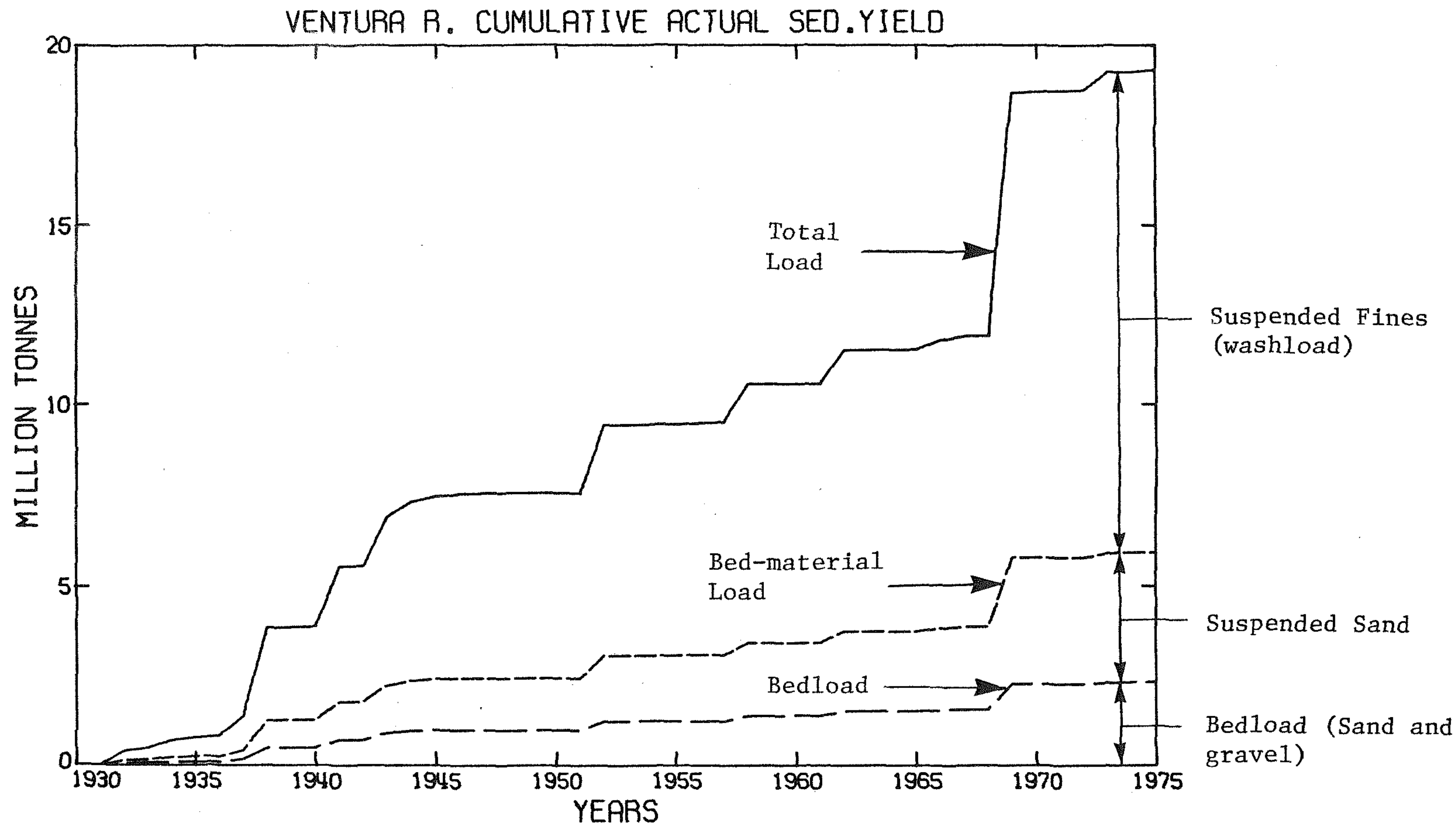

Figure C3-15 Ventura River cumulative sediment yield by mode of transport and size class.

survey, for example, includes the 1969 water year and, therefore, is expected to give a higher value than the yield calculation that does not include 1969. Also, the yield calculation includes the effect of the Ventura city division. However, this effect is probably not significant for the period under consideration.

C4 Santa Clara River Basin

C4.1 Drainage Basin Description

The Santa Clara River basin, with an area of 4,219 km^2, is the second largest of the eight moderately developed drainage basins in southern California. Currently the drainage from 36.5 percent of this area is affected by four water-supply dams. In addition, streamflow to the ocean is affected by the lower river diversion dam near the mouth.

The Santa Clara River (Fig. C4-1) drains the Transverse Ranges in the northern portions of Los Angeles and Ventura counties. The source of the river is Soledad Canyon in north central Los Angeles County. The mouth of the river is approximately 110 km and southwest from the source, 4 km south of the City of Ventura. There are four principal tributaries; in downstream order: Castaic, Piru, Sespe, and Santa Paula creeks, all of which enter from the north. Of these, only Sespe and Santa Paula creeks are uncontrolled, except for small diversions. Watershed elevations range from sea level to nearly 2,700 m, at Mount Piños in the headlands of Piru Creek. The lower 50 km of the river flow over a broad and sandy alluvial plain that is dry most of the year. The mean annual (1936-1974) precipitation ranges from 35 cm at the mouth to about 90 cm at San Guillermo Mountain. The vegetation within the Santa Clara Basin is dominated by chaparral, with islands of oak woodland and coastal sage scrub at lower elevations. The headlands of Piru Creek have coniferous forests at elevations over 1,500 m, with a piñon juniper woodland in the drier Lockwood Valley.

C4.2 Geologic Setting

The Santa Clara River drains an immense piece of the Transverse Ranges province and flows through possibly the most geologically diverse terrain of any river in the study area. Its headwaters lie within the eastern part of the province amid Precambrian and Mesozoic rocks of igneous and metamorphic composition. Due to their proximity to the

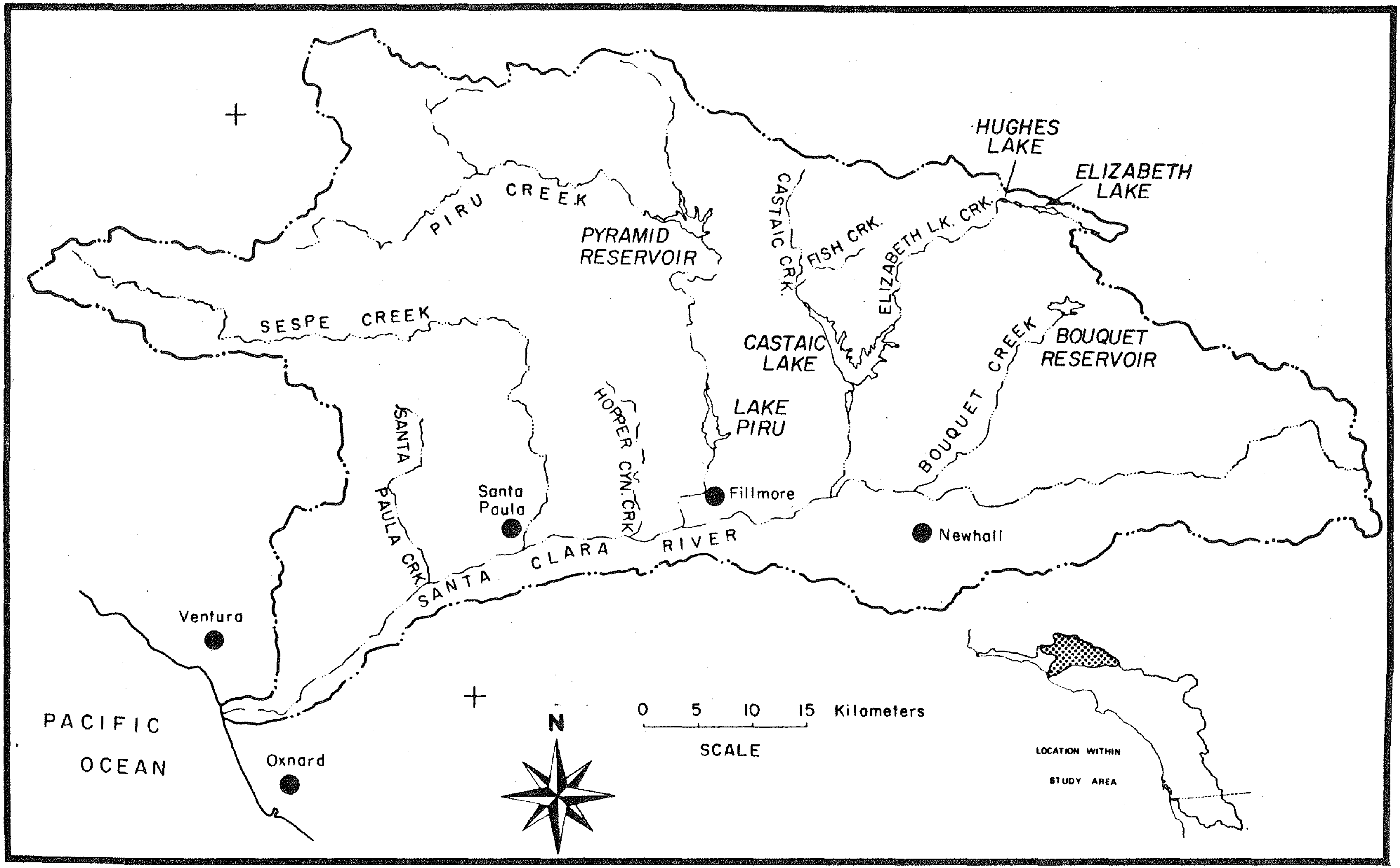

Figure C4-1 Santa Clara River basin.

San Andreas fault zone, these rocks have been greatly sheared and fractured thus provide the river channel with coarse, crystalline debris. From its headwaters the river travels west into country covered with thick folded piles of Cenozoic marine and nonmarine clastic sediments. Because their grain size on the whole is small, detritus derived from these sediments is in most cases much finer than debris coming from crystalline terrain to the east. As it approaches the coast the river traverses a wide alluviated lowland where it dumps much of its coarser load before emptying into the sea.

Faulting and folding have defined the east-west structural grain of the Transverse Ranges and in large part have constrained drainage development within the province. The Santa Clara River is no exception; it flows its entire length down an elongate, fault-bounded syncline. The upper part, known as the Soledad basin, was once an enclosed depression much like Death Valley is today. Prior to being breached in recent times by the proto-Santa Clara River, interior drainages dumped coarse nonmarine sediments into the basin. The famous Vasquez Rocks are remnants of these deposits. The lower Santa Clara River likewise flows along the axis of a down-folded syncline bounded to the north and south by thrust faults at the bases (feet) of the Topatopa Mountains and Oak Ridge, respectively. Tributaries to the Santa Clara are also controlled by geologic structures. Sespe Creek for many miles flows east-southeast, parallel to the Pine Mountain fault and the folds associated with it. Piru Creek follows the trace of the San Gabriel fault where rocks, having been weakened by crushing along the zone, are more easily eroded.

C4.3 Control Structures

The five major streamflow control structures on the Santa Clara River basin are described in Table C4-1 and shown in Fig. C4-1. A discussion of their influence on the annual water discharge at Montalvo follows.

Table C4-1

Control Structures of the Santa Clara River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
Bouquet	45	1934	35
Lake Piru (Santa Felicia Dam)	112	May 1955	1100*
Pyramid	214	December 1971	759
Castaic Lake	399	January 1972	404

Diversion Facility	Completion Date	Diversion From/To
Lower River Diversion Dam at Saticoy, California	1929	Water diverted from the Santa Clara River to local percolation basins includes approximately 20 percent of the water stored in Lake Piru.

*Includes area controlled by Pyramid Dam since 1971.

Note: Drainage area of the Santa Clara River basin is 4,219 km^2.

Lower River Diversion Dam at Saticoy

Diversions at Saticoy have gradually increased since the dam's construction in the 1929 water year. For example, for the years 1929 to 1938 the average annual diversion was 13.9 million m^3, representing about nine percent of the natural flow, while for the years 1966 to 1975 the average annual diversion was 79.0 million m^3 or 26 percent of the projected natural flow at Nontalvo. Since the inception of the facility, records of annual diversions have been kept by the United Water Conservation District in Santa Paula, California.

Bouquet Reservoir

Bouquet Reservoir, in the northeast corner of the basin, is used primarily for storage of imported water. It controls less than one percent of the total drainage area and its influence on the annual streamflow at Montalvo has been considered negligible in the context of this report.

Lake Piru (Santa Felicia Dam)

Records of the United Water Conservation District (UWCD) indicate that, with the exception of the 1969 water year, all inflow to Lake Piru has been prevented from reaching Montalvo. During the floods of January and February 1969, the capacity of the facility was exceeded and about 140 million m^3 of water spilled. During the water years 1956 to 1971, careful estimates were made of the yield of Santa Felicia Dam, i.e., the amount of water that would have flowed to the ocean under natural conditions. These estimates obtained from UWCD were determined by calculating percolation rates for individual storms and applying these rates to the inflow to Lake Piru. Calculations for the first sixteen years of operation of the dam indicate that 50.3 percent of the average annual inflow of 53.6 million m^3 would have reached the Pacific Ocean without reservoir operation.

Pyramid Reservoir

This facility is upstream of Lake Piru and affects no additional drainage area. It was constructed as part of the California Water

Project, which imports water from northern California. As of 1975 it had not affected streamflow at Montalvo.

Castaic Lake

Water retention during construction of this facility began in November 1970, anf full operation began in June 1972. Castaic Lake was also constructed as part of the California Water Project. Current operating policy calls for releases from the reservoir that equal local natural inflow. However, the distribution of daily releases has been somewhat different from the distribution of daily inflows. Consequently, the annual flow at Montalvo has been influenced. So far, this influence has been quite small, as will be shown later in this report.

C4.4 Gaging Stations

The gaging stations in the Santa Clara basin are shown in Fig. C4-2 and listed in Table C4-2. The basin is well covered, with 38 stations, of which 16 have record lengths of 15 years or more. Three stations, two on the main channel (01 and C, Fig. C4-2) and one on Sespe Creek (W), have sediment records.

C4.5 Stream Bed Characteristics

In Fig. C4-3 the bed elevation of the Santa Clara River is plotted as a solid line against distance from the Coast. The dashed lines indicate the bed elevations of three of the major tributaries. The alluvial flood plain is illustrated by the gentle slope at the cost, which increases gradually in the upstream direction.

The gaging station nearest the ocean is also a sediment station, located at Montalvo (C), seven kilometers inland from the coast. This station intercepts runoff from more than 99 percent of the river basin's drainage area. Five composite bed material grain size analyses have been published by the USGS for August 2, 1971 to September 30, 1975.

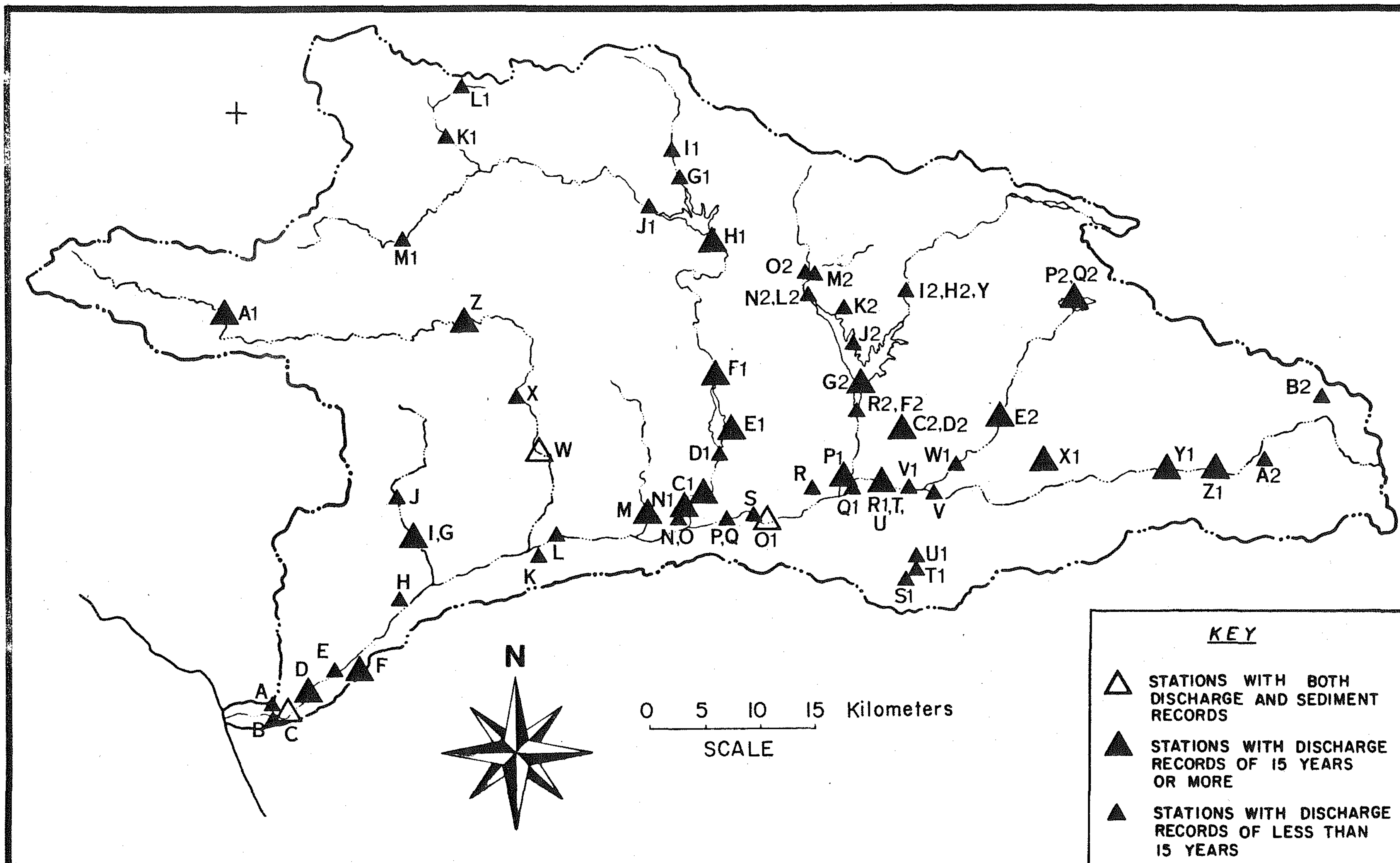

Figure C4-2 Location of streamflow and sediment gaging stations with Santa Clara River basin.

Table C4-2
Gaging Stations within the Santa Clara River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG.-MIN.-SEC.	LONGITUDE DEG.-MIN.-SEC.	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	3R	Z2-1100		MOON DRAIN	34-14-36	119-11-42	VEN	8090	SD	1968			F	3.11		L
B	3R	Z2-1130		EL RIO DRAIN	34-13-54	119-10-42	VEN	8090	SD	1968			F	3.89		L
C	1	Z2-1145	11-1140.00	SANTA CLARA R A MONTALVO	34-14-31	119-11-21	VEN	5000	SD	1927		38	E	4175.		F
D*	1	Z2-1200	11-1139.20	SANTA CLARA R A SATICOY	34-16-30	119-08-12	VEN	5000	SD	1927	1970	17	G	4131.		F
E	3R	Z2-1215		WASON BARRANCA	34-17-12	119-08-30	VEN	8090	SD	1968			F	13.0		L
F*	1	Z2-1250	11-1139.00	SATICOY DIV NR SATICOY	34-17-30	119-07-00	VEN	5411	SD	1928		30	G	4069.		L
G	1	Z2-1280		SANTA PAULA C DIV			VEN	5411	SD	1931	1941		F	104.		L
H	3R	Z2-1290		FAGEN CYN	34-20-36	119-04-36	VEN	8090	SD	1968			F	9.32		L
I*	1	Z2-1300	11-1135.00	SANTA PAULA C NR SANTA PAULA	34-23-44	119-04-32	VEN	5000	SD	1927			G	104.	195	F
J	6	Z2-1330	11-1134.00	SANTA PAULA C BL SISAR C NR ST PA	34-25-30	119-05-12	VEN	5000	SD	1911	1913		G	91.2		F
K	3R	Z2-1390		GRIMES CYN	34-22-42	118-55-06	VEN	8090	SD	1968			F	10.1		L
L	6	Z2-1400	11-1110.00	SANTA CLARA R A FILLMORE	34-23-24	118-54-54	VEN	5000	SD	1911	1912		G	3030.		L
M*	1	Z2-1480	11-1105.00	HOPPER C NR PIRU	34-24-03	118-49-32	VEN	5121	SD	1931		2	G	61.1	180	F
N	3R	Z2-1486		REAL CYN	34-25-00	118-48-06	VEN	8090	SD	1968			F	5.18		L
O	3R	Z2-1490		WARRING CYN	34-24-54	118-47-48	VEN	8090	SD	1968			F	3.63		L
P	1	Z2-1560	11-1090.00	SANTA CLARA R NR PIRU	34-24-12	118-44-18	SBD	5050	SD	1927	1932		G	1717.		F
Q	9	Z2-1565	11-1089.50	SANTA CLARA R 8 MI W CASTAIC JCT	34-24-12	118-44-18	VEN	1101	SD	1936	1948		G			L
R*	3X	Z2-1590	11-1082.00	SANTA CLARA R TRIB NR VAL VERDE	34-25-30	118-36-48	LAX	5000	SD	1959	1973		G	1.68		F
S	1	Z2-1600	11-1084.00	SANTA CLARA R 1/2 MI W LA CO LINE	34-24-06	118-41-54	VEN	1101	SD	1948	1953		F	1667.		L
T*	1	Z2-1700		SANTA CLARA R A OLD HWY BR	34-25-36	118-35-12	LAX	1101	SD	1956			F	1062.		L
U*	1	Z2-1702		SANTA CLARA R A HWY 99	34-25-36	118-35-06	LAX	1101	SD	1938	1956		F	1062.		L
V	1	Z2-1740	11-1078.00	SANTA CLARA R BOUQUET CYN RD SAUG	34-25-18	118-32-18	LAX	1101	SD	1931	1938		G			L
W*	1	Z2-2150	11-1130.00	SESPE C NR FILLMORE	34-27-03	118-55-30	VEN	5000	SD	1911		14	G	650.	177	F
X	1	Z2-2250	11-1120.00	SESPE C NR SESPE	34-30-12	118-57-24	VEN	5000	SD	1915	1927		G	544.		F
Y*	1	Z2-2330	11-1080.70	ELIZABETH LK CYN C AB CASTAIC	34-33-42	118-34-12	LAX	5050	SD	1961			F	159.		L
Z*	1	Z2-2400	11-1119.00	SESPE C WEST OF SESPE HOT SPRINGS	34-34-18	119-00-42	VEN	8090	SD	1953			F	150.		L
A1*	1	Z2-2645	11-1115.00	SESPE C NR WHEELER SPRINGS	34-34-40	119-15-25	VEN	5000	SD	1948			G	128.	1067	F
B1*	1	Z2-2930	11-1125.00	FILLMORE IRR CO CA NR FILLMORE	34-27-15	118-55-29	VEN	5000	SD	1927		3	G		201	F
C1*	1	Z2-3150	11-1100.00	PIRU C NR PIRU	34-25-30	118-45-12	VEN	5000	SD	1911	1974	14	G	1132.		F
D1*	1	Z2-3240	11-1098.00	PIRU C BL SANTA FELICIA DAM	34-27-37	118-45-04	VEN	5000	SD	1955			G	1098.	262	F
E1*	8R	Z2-3375	11-1097.00	PIRU LK NR PIRU	34-27-52	118-44-57	VEN	5411	SD	1955			G	1100.		F
F1*	1	Z2-3480	11-1096.00	PIRU C AB PIRU LK	34-31-23	118-45-22	SBD	5000	SD	1955			G	963.	321	F
G1	9	Z2-3700	11-1095.00	PIRU C LOS ALA DMS NR GORMAN	34-39-12	118-46-18	LAX	4740	SD	1920	1923	2	E	707.		F
H1*	1	Z2-3750		PIRU C AB FRENCHMAN FLAT	34-37-48	118-44-48	VEN	5050	SD	1963			E	769.		S
I1	1	Z2-3770		CANADA DE LOS ALAMOS BL APPLE CN	34-40-42	118-47-00	LAX	5050	SD	1965	1969		E			SF
J1	1	Z2-3790		PIRU C BL BUCK C	34-39-54	118-49-18	LAX	5050	SD	1965			E			SF
K1	1	Z2-3830	11-1092.50	LOCKWOOD C A GORGE NR STAUFFER	34-43-57	119-02-14	VEN	5000	SD	1971			E	152.	1460	F
L1	1	Z2-3850	11-1092.00	LOCKWOOD C.MF. NR STAUFFER	34-45-56	119-07-12	VEN	5000	SD	1971			E	14.3	1686	F

(*) denotes stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

Table C4-2 (continued)

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°-MIN'-SEC"	LONGITUDE DEG°-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
M1	1	Z2-3890	11-1091.00	PIRU C BL THORN MEADOWS NR STAUFF	34-38-21	119-05-43	VEN	5000	SD	1971			E	58.3	1469	F
N1*	1	Z2-3910	11-1100.50	PIRU SPDG DIV A PIRU	34-24-36	118-47-24	VEN	5411	SD	1931		20	G	1122.		L
O1*	1	Z3-1135	11-1085.00	SANTA CLARA R A LA-VEN COUNTY LIN	34-23-59	118-42-14	LAX	5000	SD	1952			G	1668.	242	F
P1*	1	Z3-1250	11-1081.45	CASTAIC C NR SAUGUS	34-25-42	118-37-40	LAX	5000	SD	1945			F	525.		L
Q1	9	Z3-1350	11-1080.20	SANTA CLARA R 1 MI W CASTAIC JCT	34-25-48	118-37-06	LAX	1101	SD	1930	1936		G			L
R1*	1	Z3-1380	11-1080.00	SANTA CLARA R OLD HY BR NR SAUGUS	34-25-30	118-35-12	LAX	1101	SD	1929	1950		G	1065.		F
S1	9	Z3-1430	11-1078.95	RICE CYN C NR NEWHALL	34-21-00	118-32-42	LAX	1101	SD	1931	1934		G			L
T1	9	Z3-1460	11-1079.05	GAVIN CYN C NR NEWHALL	34-21-30	118-32-12	LAX	1101	SD	1931	1933		G			L
U1	9	Z3-1480	11-1079.12	GAVIN CYN C A WELDON CYN HWY NR NW	34-22-00	118-32-12	LAX	1101	SD	1931	1940		G			L
V1*	1	Z3-1500	11-1079.22	PLACERITA C A HY SF SC R NR NHALL	34-24-54	118-32-36	LAX	1101	SD	1947			F	106.		L
W1	1	Z3-1550	11-1078.60	BOUQUET C NR SAUGUS	34-26-56	118-30-22	LAX	5000	SD	1970			E	134.		F
X1*	1	Z3-1595	11-1077.70	MINT CYN C A FITCH AVE NR SAGUS	34-26-48	118-25-36	LAX	1101	SD	1956			F	69.7		L
Y1*	1	Z3-1710	11-1077.45	SANTA CLARA R AB RR STA A LANG	34-25-52	118-21-22	LAX	5000	SD	1929			G	407.		L
Z1*	9	Z3-1810	11-1077.25	SANTA CLARA R 1 MI BL RAVENNA	34-26-12	118-14-36	LAX	1101	SD	1951			G			L
A2	1	Z3-1835		ALISO CYN C NR BLUM RANCH	34-27-42	118-09-24	LAX	1101	SD	1966			G	61.4		L
B2	3X	Z3-1850	11-1077.00	SOLEDAD CYN TRIB NR ACTION	34-29-18	118-06-56	LAX	5000	SD	1959	1973		G	10.6		F
C2*	1	Z3-1915	11-1078.65	DRY CYN C BL RES NR SAUGUS	34-28-54	118-31-18	LAX	1200	SD	1916	1961		G			L
D2*	1	Z3-1925	11-1078.70	DRY CYN C SEEPAGE BL RES NR SAUGU	34-28-42	118-32-00	LAX	1200	SD	1933	1965		G			L
E2*	9	Z3-2200	11-1078.50	BOUQUET C AB TEXAS CYN NR SAUGUS	34-30-42	118-26-00	LAX	1101	SD	1948			G			L
F2		Z3-2245		HUGHES LK RELOCATION BR	34-30-06	118-36-48	LAX	5050	SD	1968			E			SF
G2*	9	Z3-2260	11-1081.20	CASTAIC C A ELIZ LK CYN HWY NR CA	34-31-18	118-36-24	LAX	1101	SD	1933			G			L
H2*	9	Z3-2320	11-1080.70	ELIZABETH LK C AB DRY GUL CASTAIC	34-33-30	118-34-18	LAX	1101	SD	1931			G			L
I2*	1	Z3-2330	11-1081.30	ELIZABETH LK CYN C AB CASTAIC	34-33-24	118-34-12	LAX	5000	SD	1961			E	113.2	510	SF
J2	1	Z3-2340	11-1080.55	NECKTIE CYN C AB CASTAIC	34-33-36	118-36-48	LAX	5050	SD	1967			E	5.49	475	SF
K2	1	Z3-2345		ELDERBERRY CYN C AB CASTAIC C	34-34-18	118-37-30	LAX	5050	SD	1966			E	6.99		S
L2	1	Z3-2360		CASTAIC C AB CORDOVA RANCH	34-35-48	118-39-48	LAX	5050	SD	1961	1969		P	166.		L
M2	1	Z3-2370	11-1080.80	FISH C AB CASTAIC C	34-36-12	118-40-18	LAX	5050	SD	1965			E	70.4	494	SF
N2	1	Z3-2375		FISH C BL CIENEGA CG	34-37-00	118-38-42	LAX	5050	SD	1964			E			SF
O2	1	Z3-2385		CASTAIC C AB FISH C	34-36-12	118-40-06	LAX	5050	SD	1965	1968		E			SF
P2	1	Z3-2388	11-1080.75	CASTAIC C 1 MI A FISH C	34-36-54	118-39-28	LAX	5050	SD	1968			E	93.2	543	SF
Q2*	1	Z3-2930	11-1078.25	BOUQUET RES CFL NR GREEN VALLEY	34-35-18	118-23-48	LAX	1200	SD	1934			G	35.2		L
R2*	1	Z3-2940	11-1078.20	BOUQUET RES IF NR GREEN VALLEY	34-35-18	118-23-48	LAX	1200	SD	1934			G	35.2		L
S2	1	Z3-3333	11-1081.35	CASTAIC LAGOON PARSHALL FL	34-29-31	118-36-26	LAX	5050	SD	1972			E	357.	347	SF

(*) denotes stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

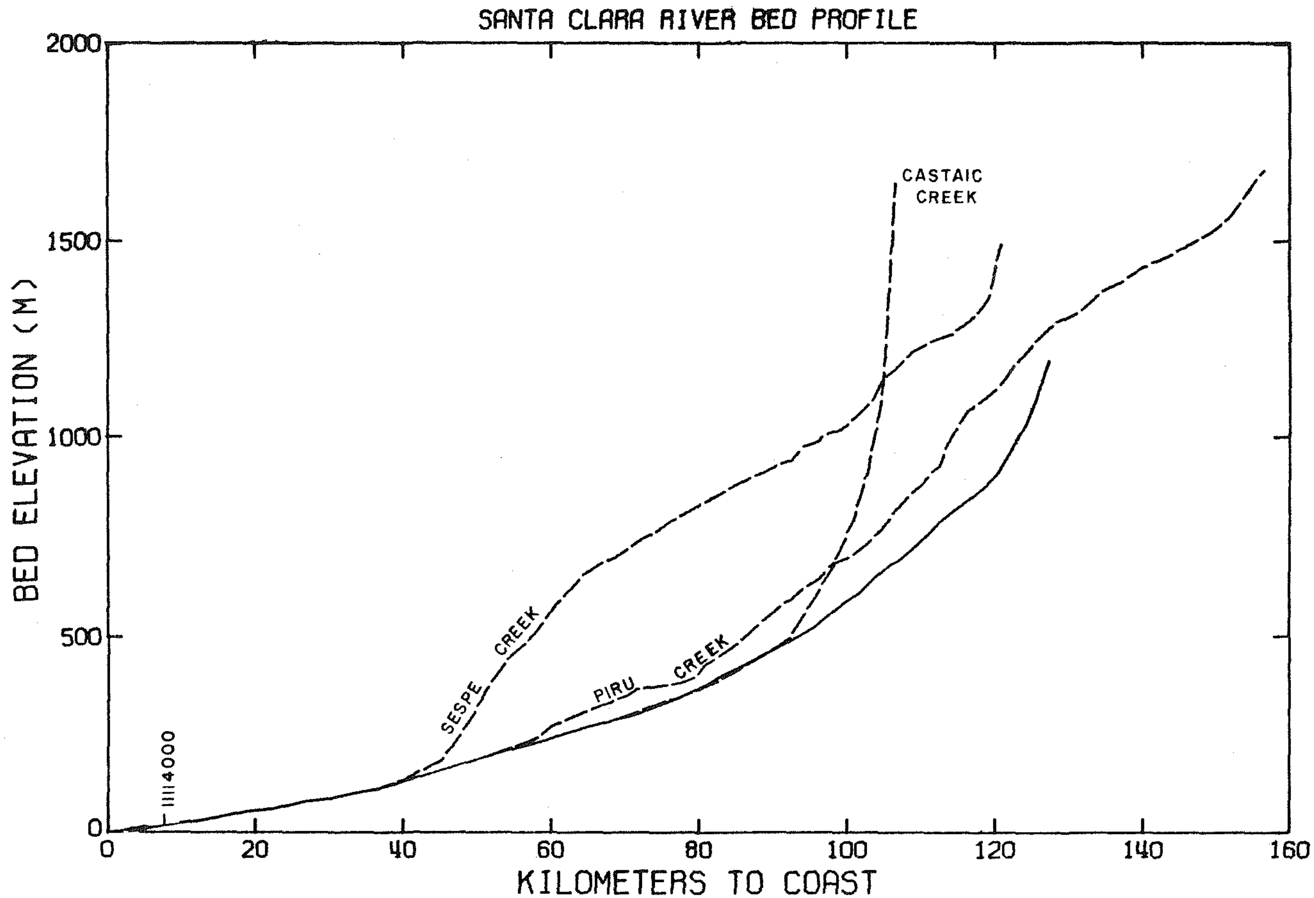

Figure C4-3 Bed profile of main Santa Clara River channel (solid line) and three tributaries (dashed lines).

The samples have an average median diameter of 1.0 mm and an average geometric standard deviation of 3.5. The grain-size distribution curves are shown in Fig. C4-4. The local bed slope at the station is 2.44 m/km.

The lower reach of the Santa Clara River (Fig. C4-5) flows over a broad alluvial flood plain. A number of sand and gravel mining operations exist on the lower reach of the river. While these operations undoubtedly have some influence on the sediment transport, they have not been considered here. Nor has the effect of the levee near the mouth been considered, although such a levee prohibits spreading of the sediment over the lower flood plain. It has been assumed that the sediment flow at Montalvo is approximately equivalent to the sediment flow to the Pacific Ocean.

C4.6 Sediment Rating Curves

In order to estimate actual suspended sediment yields from daily streamflow data, a rating curve (Fig. C4-6) was developed from instantaneous concentration data published by the USGS. Of the 82 published samples collected between January 1, 1969, and September 29, 1976, 32 were collected for low flow periods (most less than 0.1 m^3/s) between January 26, 1972 and January 16, 1973. They were eliminated because their high suspended sediment concentrations were due mainly to sluicing of gravel mining operations.* Three other samples with flows less than 0.1 m^3/s are shown in Fig. C4-6, but were not used in the curve fitting procedure (outlined in Section C18.1) because they were considered too low to be of importance in the present context. It should be noted that the high concentrations produced by the slucing of the gravel mining operation were responsible for less than one percent of the

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*Rhea P. Williams, USGS, personal communication

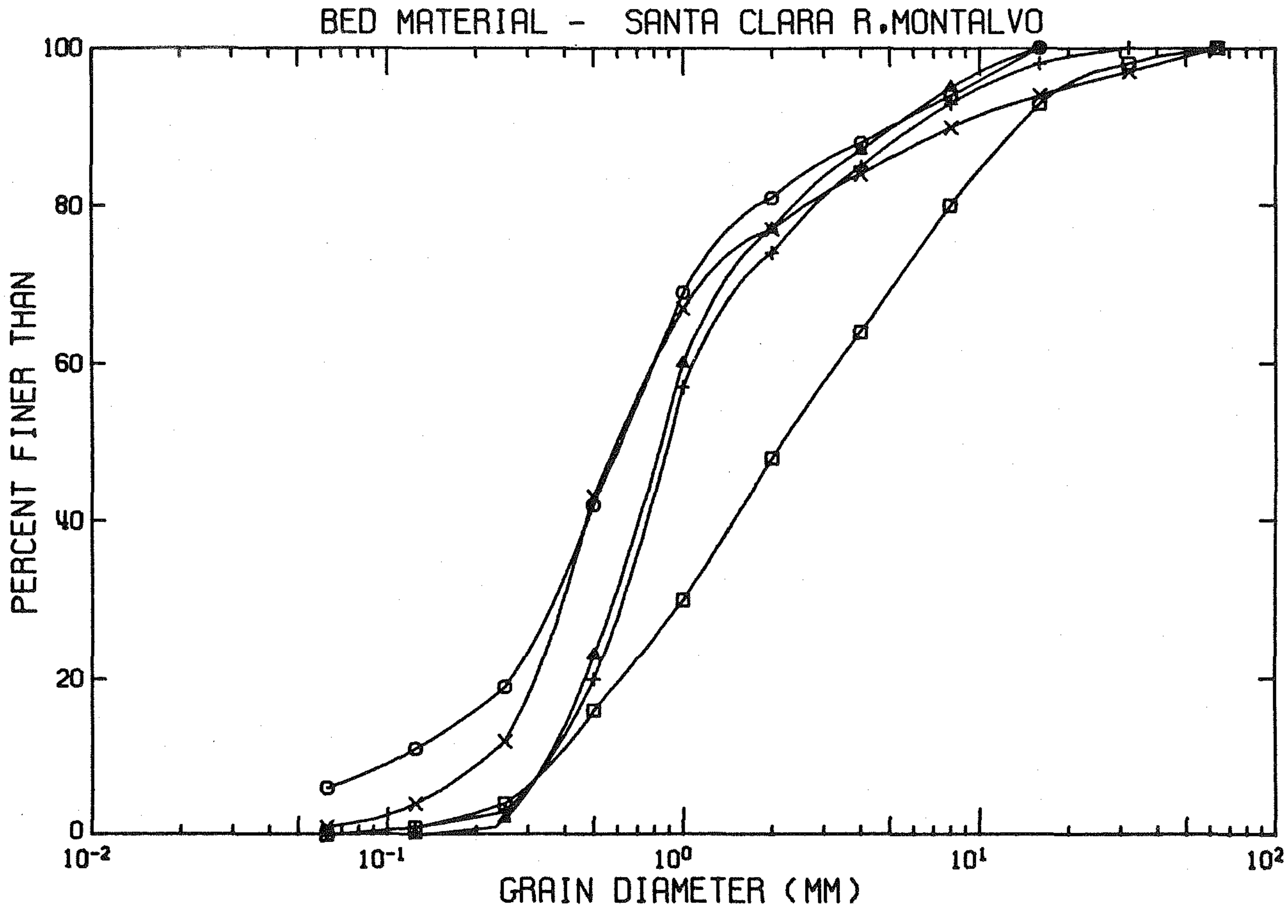

Figure C4-4 Composite bed material samples collected at station 11114000, between August 2, 1971, and September 30, 1975.

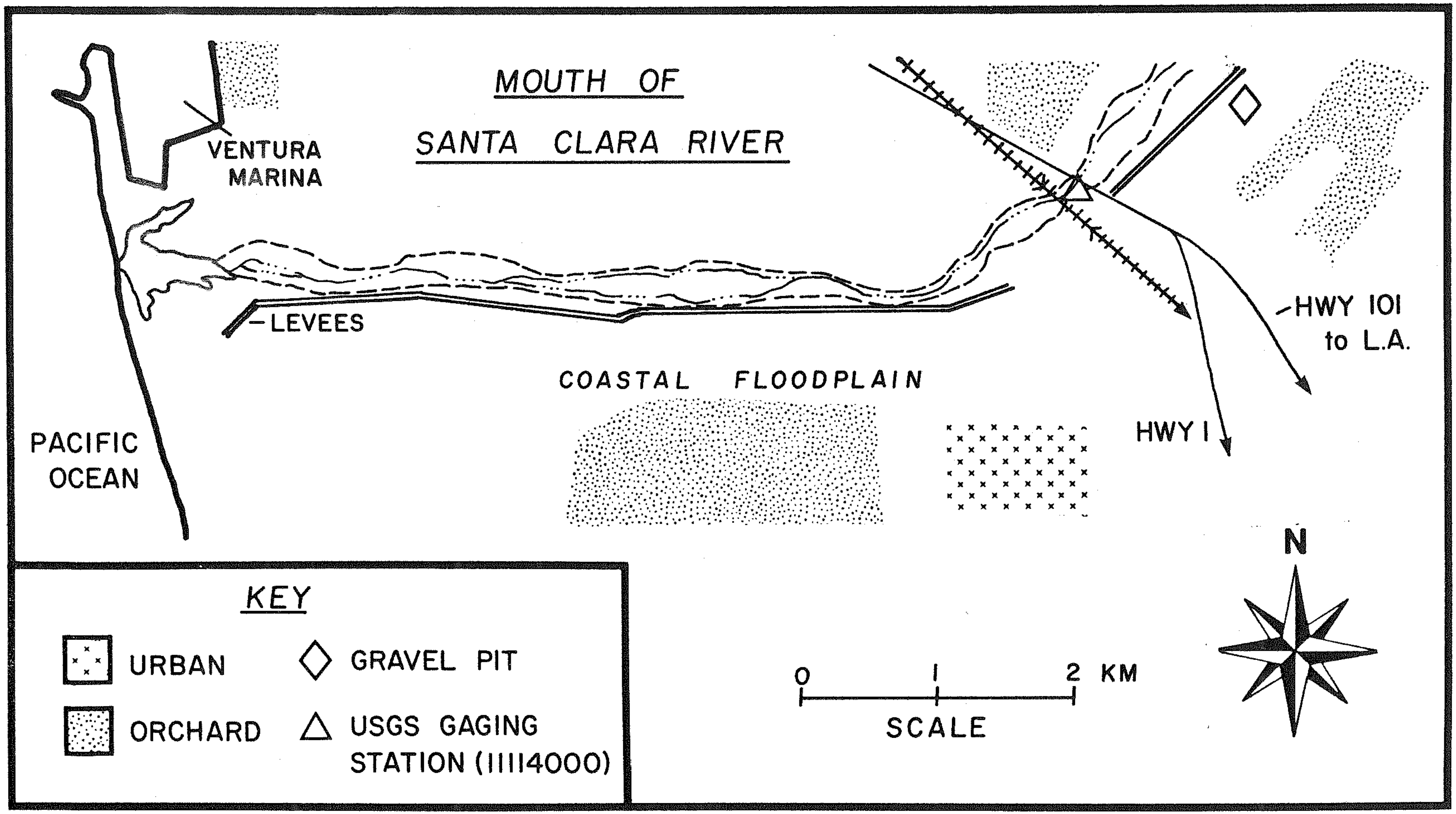

Figure C4-5 Lower reach of Santa Clara River.

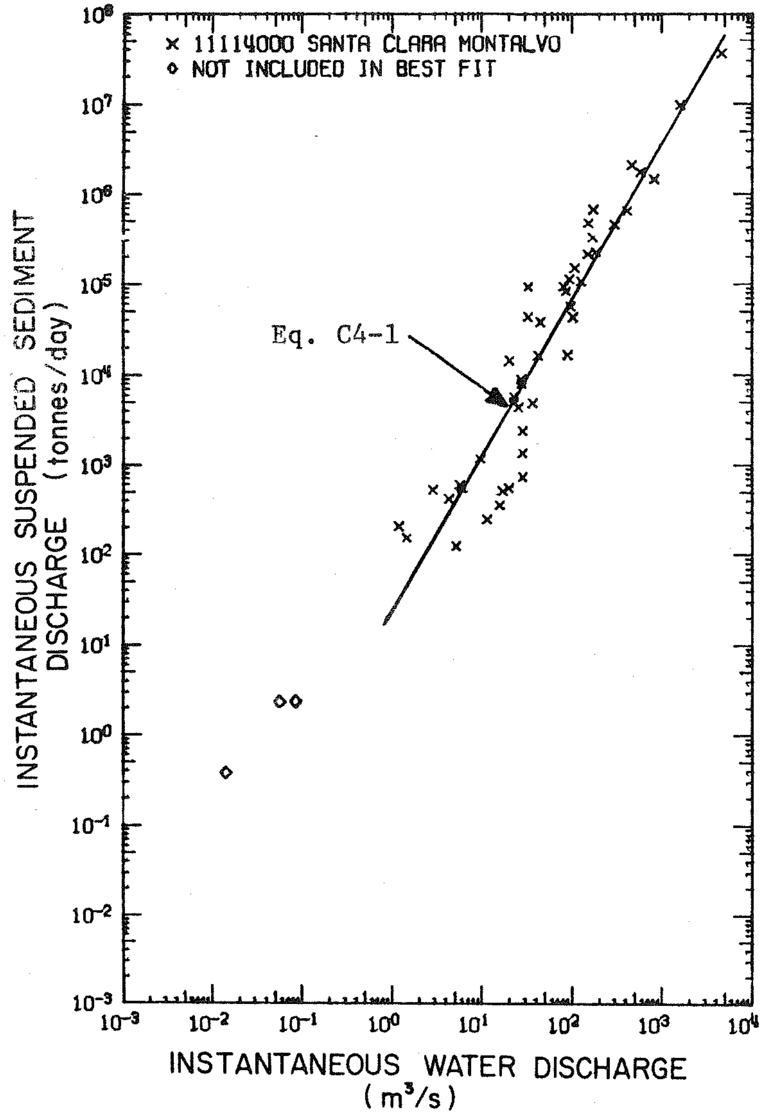

Figure C4-6 Relation of instantaneous sediment discharge to water discharge at Santa Clara River station 11114000, 1969-76.

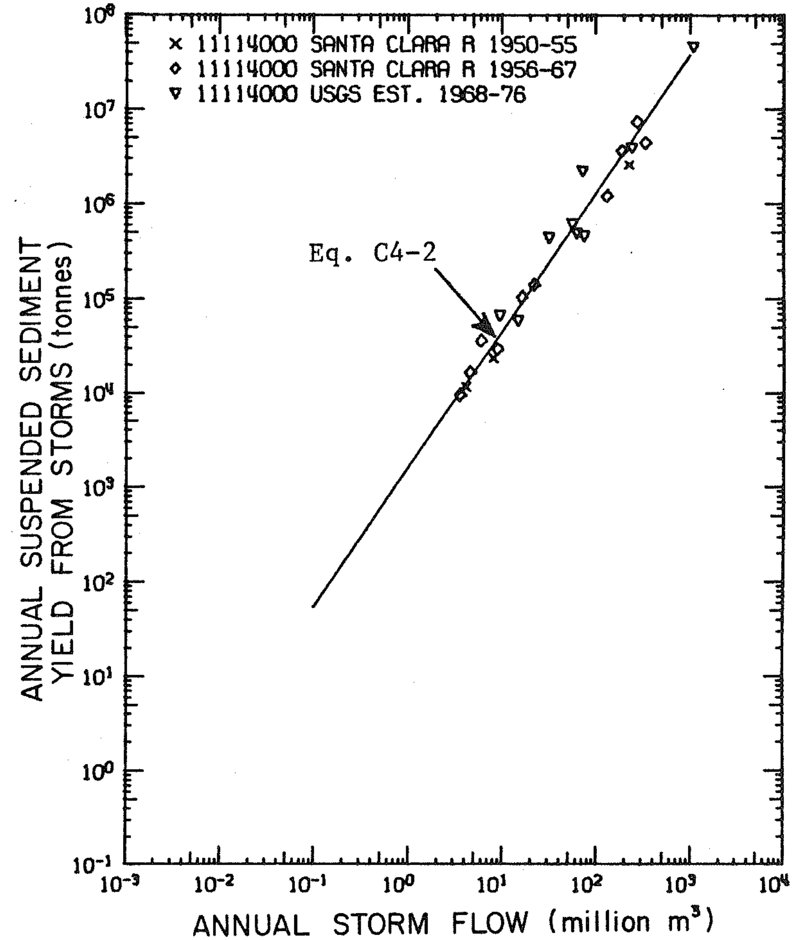

Figure C4-5 Relation of annual suspended sediment delivered by storms to annual storm flow at Santa Clara River station 11114000, 1950-76.

total suspended sediment discharge for the 1972 water year. The rating curve is given by

$$\hat{Q}_{ss} = 24.4\ Q^{1.73} \qquad \text{(C4-1)}$$

where $\hat{Q}_{ss}$ is the predicted suspended sediment transport rate in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of Q_s and Q is 0.942.

In order to estimate natural annual sediment yields and actual annual sediment yields where daily streamflow data is unavailable, a relation between annual suspended sediment and annual runoff was derived. As on the Ventura River, base flows (considered as mean daily flows less than 10 m^3/s) and corresponding daily suspended sediment yields have been removed from the annual runoff and sediment yield values, respectively, to improve the correlation. The relationship between predicted annual suspended sediment generated by storms and annual stormflow is given by

$$\hat{\forall}_{ss}(\text{storm}) = 1570\ [\forall(\text{storm})]^{1.46} \qquad \text{(C4-2)}$$

where $\hat{\forall}_{ss}$(storm) is the predicted annual suspended sediment delivered by storms and $\forall$(storm) is the annual storm runoff. Equation C4-2, derived by the method explained in Section C18.2, is illustrated in Fig. C4-7. The data in the figure is plotted in three groups. The first two groups represent estimates generated from daily flow records and Eq. C4-1, for before and after the construction of Santa Felicia Dam. The third group is composed of the available USGS estimates.

C4.7 Natural and Actual Flows

The major obstacle in evaluating natural versus actual streamflow at Montalvo has been the fact that no data were collected at this station during the years 1933 through 1950 (see Table C4-2). The procedure used to overcome this problem is outlined here.

Step 1: Construction of Annual Natural Flows

Natural flows can be constructed by combining actual flows with diversions at Saticoy and then considering the effects of Lake Piru and Castaic Lake.

Lake Piru (Santa Felicia Dam)

The yield from this facility represents water that has been used primarily for groundwater recharge and irrigation, rather than being allowed to flow to the ocean. Therefore, the yield can be added directly to the actual flow at Montalvo, plus the diversion at Saticoy, to estimate the natural flow. A portion of the annual release from the dam is channeled through the Saticoy diversion and therefore has already been considered and so must be subtracted from the above summation. The necessary data for this correction for the years 1956 through 1971 are available from the United Water Conservation District (UWCD).

There are two problems in estimating the effect of Santa Felicia Dam for 1972 through 1975. First, Pyramid Dam, upstream from Lake Piru, affects the distribution of inflows to Lake Piru, making yield calculations difficult, since they must be calculated on a storm-by-storm basis. Second, no record was kept of the distribution of releases for this period. To estimate the yields for this period, a factor of .503 was applied to the corrected inflow to Lake Piru, where the factor is the ratio of average yield to average inflow for 1956-1971. The corrected inflow was calculated as 1.1425 times the flow on Piru Creek above Lake Piru (USGS Station 11109600). This factor, determined by the UWCD, is based on the larger drainage area at the dam and the slightly higher mean annual precipitation over the larger area. On the average, for 1956-1971, 19.8 percent of the annual yield passed through the diversion at Saticoy. This figure was applied to the yield for 1972-1975 to estimate the diverted portion of the release.

Table C4-3

Estimated Percolation Rates Between Castaic Reservoir and Saticoy*

Mean Daily Flow m^3/s	Percolation Rate (%/km) Upper 45 km	Lower 18 km
0 to 3	1.8	> 1.25
3 to 14	1.57	1.09
14 to 28	0.456	0.317
> 28	0.155	0.106

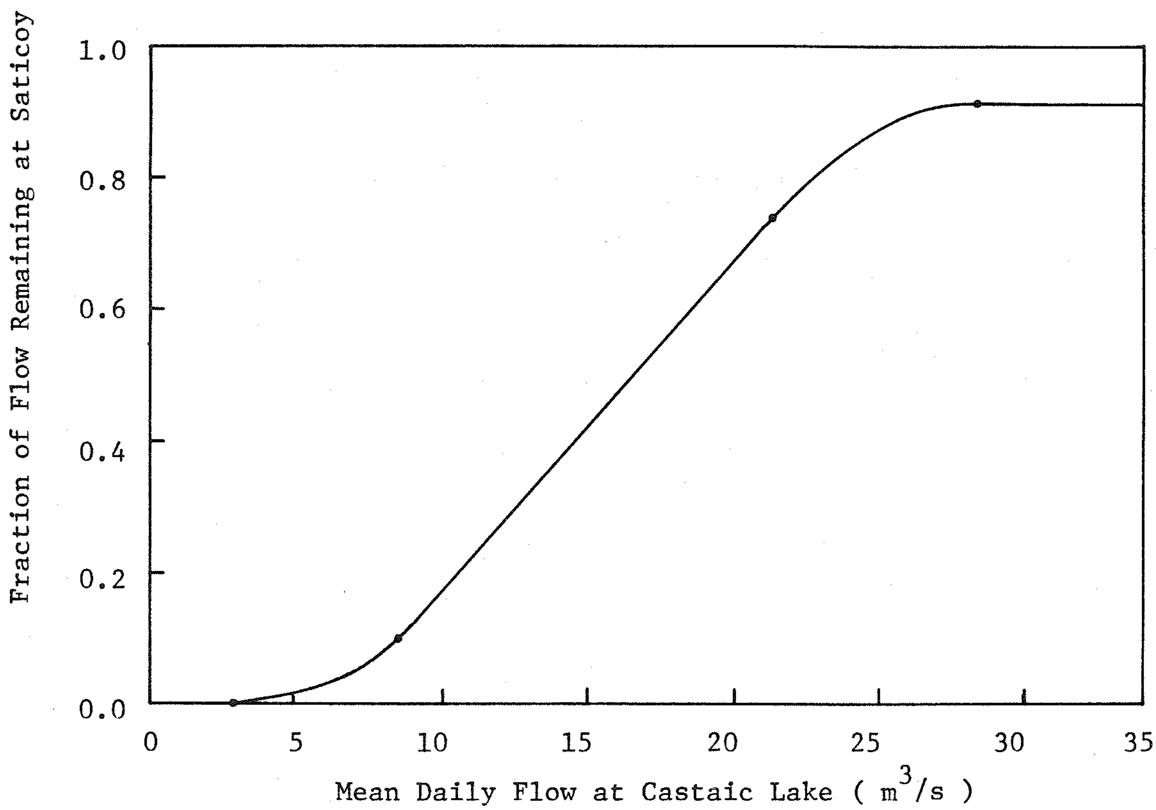

Figure C4-8 Percolation losses between Castaic Lake and Saticoy. Plotted as the fraction of mean daily Castaic Lake flow remaining at Saticoy versus mean daily flow at Castaic Lake.*

*Data supplied by the United Water Conservation District.

Castaic Lake

To examine the influcnce of this reservoir, mean daily inflows were compared with mean daily releases. These flows were then reduced to account for percolation between Castaic Lake and Saticoy. The percolation rates used, calculated by the UWCD, are given in Table C4-3. These rates were plotted on a continuous curve, Fig. C4-8, relating the fraction of the original flow remaining at Saticoy as a function of mean daily flow at the reservoir. According to these calculations, in the short period under consideration, Castaic Lake seems to have had very little effect in reducing the annual flow at Montalvo. For example, releases of large amounts of water on February 11 and 13 of 1973 caused an increase of the actual annual flow over the probable natural flow without Castaic Lake for the 1973 water year. Percolation losses between Saticoy and Montalvo, 9 km downstream, have been neglected here and in other calculations, as they are believed to be small.

Combined Effects

The procedure for calculating the natural flow can be summarized by the following equation:

Natural Flow = Actual Flow + Diversion at Saticoy
+ Yield to Basin from Lake Piru (1956-1975)
- Lake Piru Releases Diverted at Saticoy (1956-1975)
+ Natural Flow to Ocean from Castaic Lake (1971-1975)
- Actual Flow to Ocean from Castaic Lake (1973-1975) (C4-3)

Step 2: Reconstructing Missing Natural Flows, 1933-1950

To reconstruct natural flows at Montalvo for the years 1933-1950, a correlation between natural flows at Montalvo and the combined flows of Piru Creek at Santa Felicia Dam and Sespe Creek near Fillmore (USGS station 11113000, including Fillmore Irrigation Company's canal) for the years 1928-1932, 1951-1971 was used. Several other single and multiple regression correlations were tested, including flow in Santa Paula Creek, but all others yielded lower correlation coefficients.

The Piru Creek record had to be constructed from two records. USGS Station 11110000, slightly below Lake Piru, was used for the years 1928-1955. This record was multiplied by a factor of .9725 to compensate for the smaller drainage area at Santa Felicia Dam. For the period 1956-1971 the inflow to Lake Piru was used, as calculated by the UWCD from monthly change in storage and evaporation.

The final regression equation that was used is given by

$$\hat{\forall}_M = 0.397 \, \forall_{SP}^{1.2} - 3.51 \qquad \text{(C4-4)}$$

where $\hat{\forall}_M$ is the predicted natural annual flow at Montalvo and $\forall_{SP}$ is combined annual flows of Sespe and Piru creeks, in million m^3. The correlation coefficient between $\forall_M$ and $\forall_{SP}^{1.2}$ is 0.996. The equation, plotted with data in Fig. C4-9, was determined by the method of Section C18.3.

Step 3: <u>Actual Flows 1933-1950</u>

Having estimated the natural flow at Montalvo for 1933-1950, the actual flow can be obtained by subtracting the diversion at Montalvo. This calculation is appropriate because Santa Felicia Dam had not yet been constructed.

Step 4: <u>Estimation of Base Flows</u>

For the water years 1950-1975 natural and actual base flows were estimated as follows: Since mean daily flows are available on magnetic tape, actual annual base flows (defined as mean daily flows less than 10 m^3/s, see Fig. C4-10) could be found directly by combination of daily values and application of appropriate conversion factors. Estimation of natural base flows was slightly more complicated.

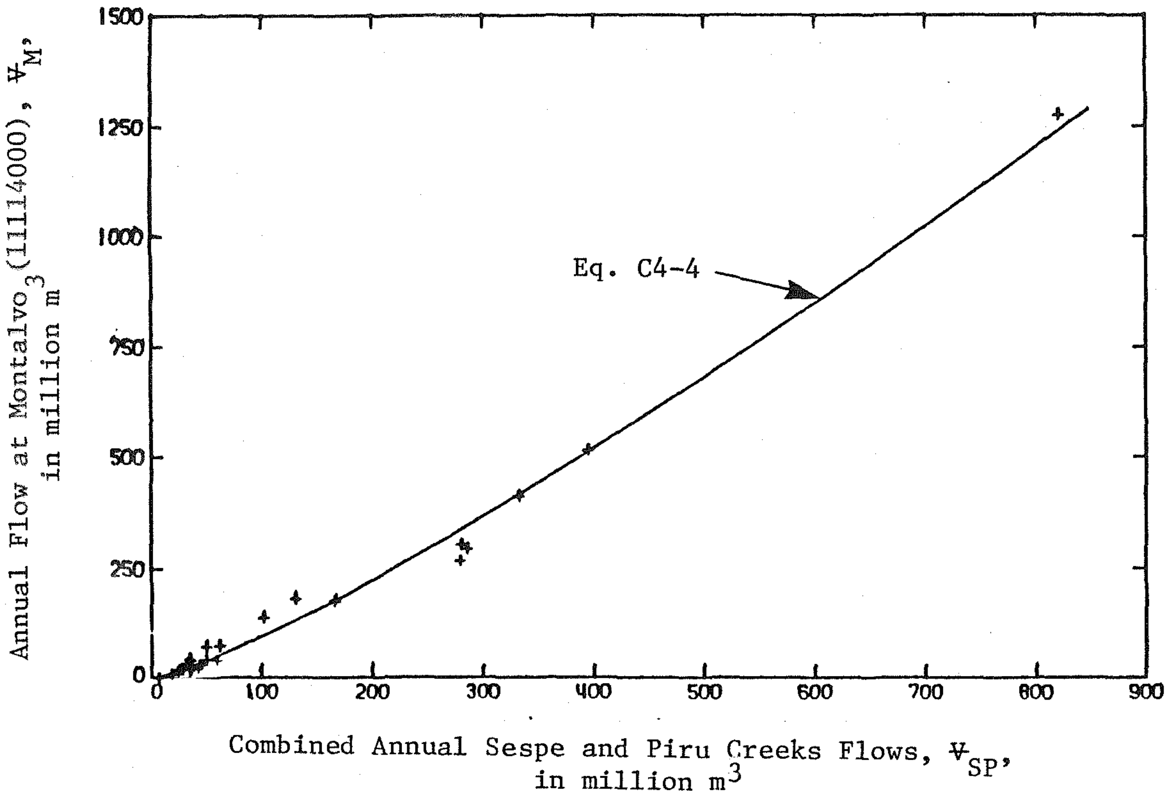

Figure C4-9 Correlation between annual flows on the Santa Clara River at Montalvo (11114000), near the mouth, with combined natural annual flows on Sespe Creek and Piru Creek for the period 1928-32 and 1950-75.

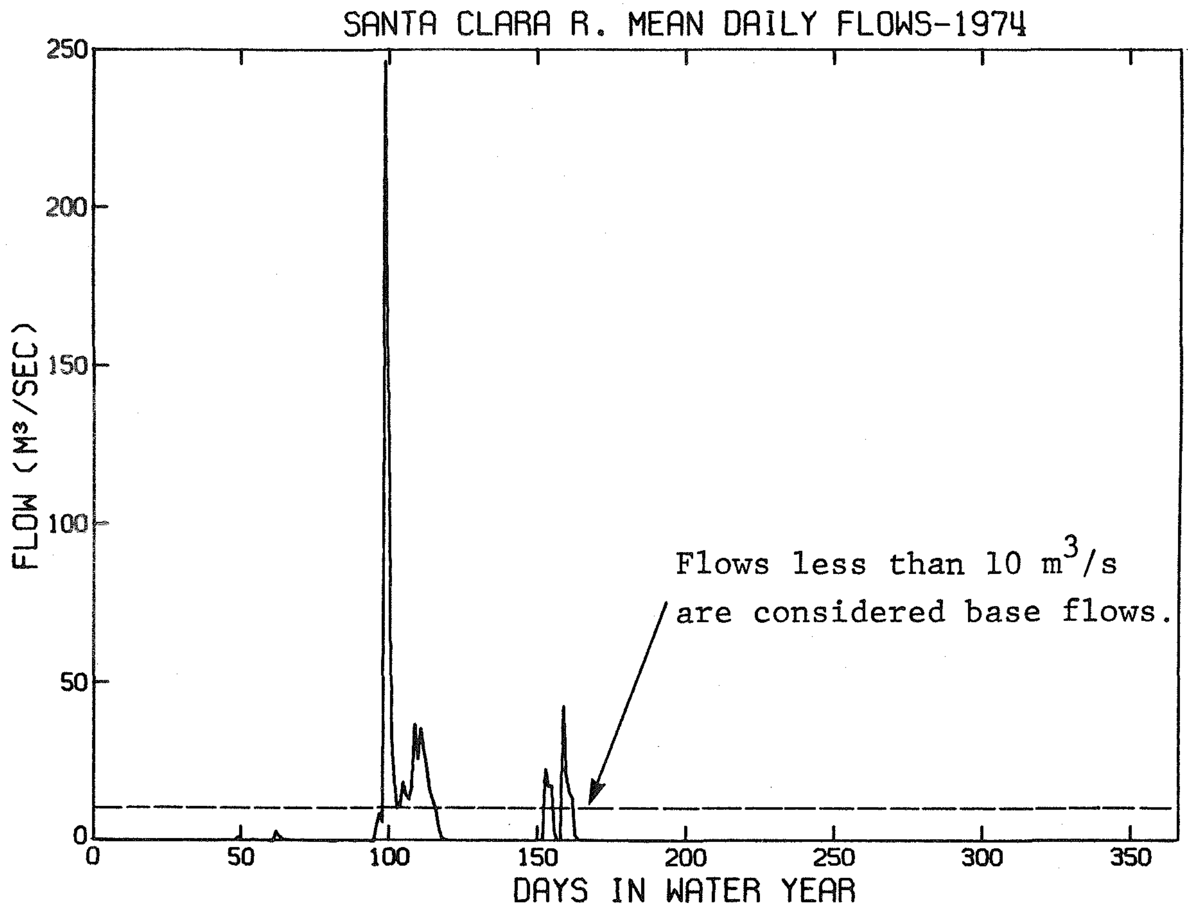

Figure C4-10 Typical annual sequence of mean daily flows (1974 water year) showing chosen cutoff between base flows and storm flows.

The diversion facility at Saticoy, with a capacity of about 10 m^3/s, was designed primarily to divert base flows and generally does not operate during storm flow periods. However, the diversion is also used as a conduit for some of the releases from Lake Piru (Santa Felicia Dam), which under natural conditions would probably have been storm flow. Therefore, the natural annual base flow for a given year can be estimated as the sum of the actual annual base flow plus the annual diversion at Saticoy, minus the annual Lake Piru release diverted at Saticoy.

For the water years prior to 1950 no daily flow data are available and so some statistical method of estimating both natural and actual base flows was required. In Fig. C4-11 natural base flows are plotted as a function of natural total flows for the period 1950-1975. An equation was fitted by eye which could be used to predict natural base flows. The equation,

$$\hat{\forall}_B(\text{nat}) = \frac{\forall(\text{nat})}{0.0092\ \forall(\text{nat}) + 1} \tag{C4-5}$$

where $\hat{\forall}_B(\text{nat})$ is the predicted natural base flow and $\forall(\text{nat})$ is total natural flow, was fitted in such a way that for very low flow years the base flow would approximately equal the total flow and for very high flow years the base flow would approach a constant value (about 110 million m^3). After using Eq. C4-5 to predict natural base flows prior to 1950, the actual base flow was calculated by subtracting the diversion at Saticoy from the natural base flow.

C4.8 Annual Suspended Sediment Yield

The total annual suspended sediment yield is a combination of the suspended sediment produced by base flows and storm flows. With the use of the annual rating curve (Eq. C4-2) the natural (1928-1975) and actual (1928-1949) suspended sediment yields, produced by storm flows, can be predicted. The corresponding base flow suspended sediment yields can be estimated using an average concentration of 840 mg/ℓ.

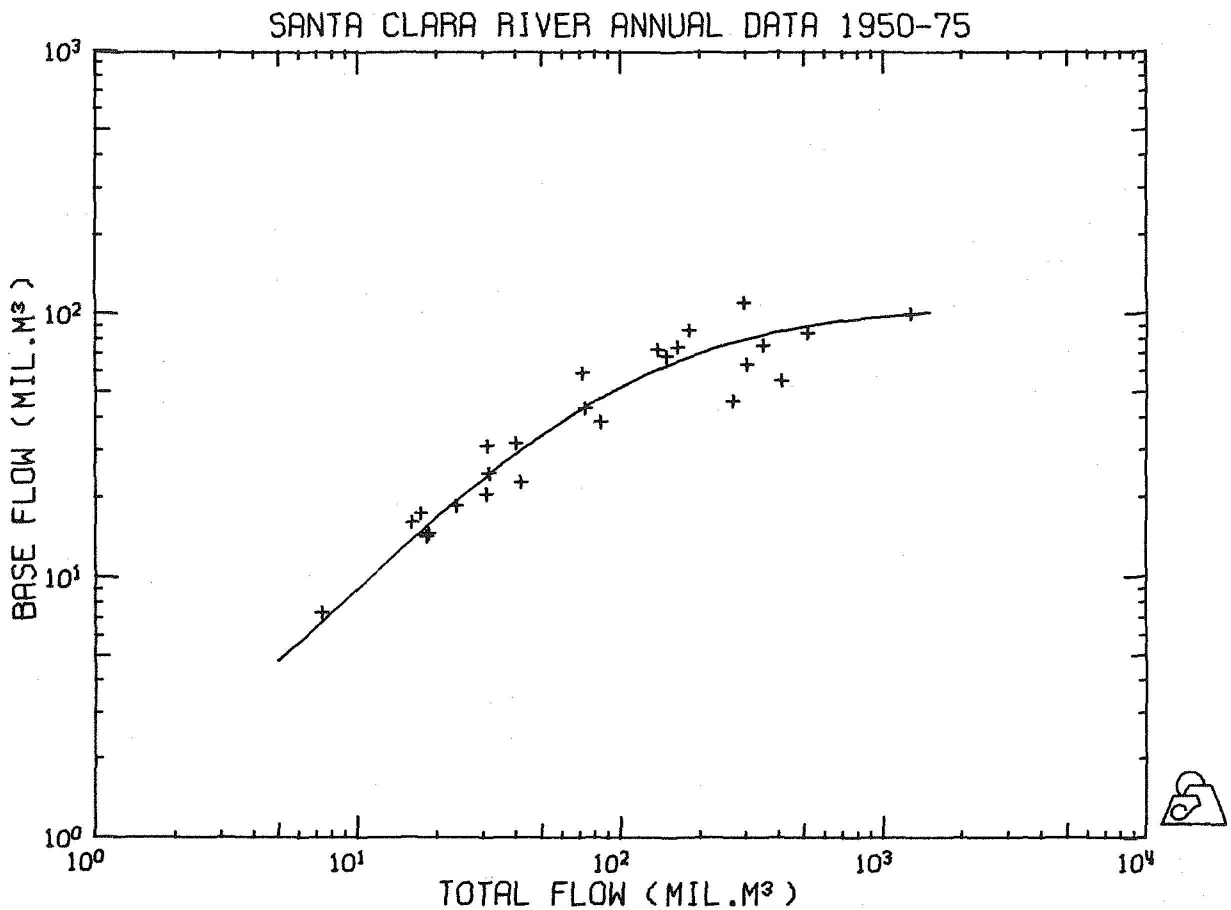

Figure C4-11 Relation between actual base flows and actual total flows, 1950 to 1975.

This concentration is the predicted average concentration for actual base flows for 1950-1975. The detailed results are given in Table C4-4, and total cumulative suspended sediment yields are tabulated in Table C4-5 and plotted in Fig. C4-12.

C4.9 Annual Sand in Suspension

As mentioned in Section C3.9, the quantity of sand in suspension is very difficult to measure accurately. However, sufficient data is available to make reasonable estimates of annual suspended sand production. The available data for instantaneous suspended sand transport plotted as a function of water dishcarge in Fig. C4-13. The data samples are the same as those plotted in Fig. C4-6, except that only the fraction coarser than 0.062 mm is plotted. Equation C4-1, represented by the dashed line on Fig. C4-13, is the best fit equation for total suspended load. A curve made up of two straight line segments on the log-log plot was fitted to the suspended sand data. For discharges (Q) greater than 100 m^3/s, the equation is

$$\hat{Q}_{ss-sand} = 6.46\ Q^{3.64}, \text{ for } Q > 100\ m^3/s \qquad (C4\text{-}6a)$$

where $\hat{Q}_{ss-sand}$ is the predicted suspended sand transport rate in tonnes/day. The exponent in Eq. C4-6a was set equal to the exponent of Eq. C4-1, and the coefficient was determined from Eq. C18-7b of Section C18.1. For discharges less than or equal to 100 m^3/s, the equation

$$\hat{Q}_{ss-sand} = 0.0185\ Q^{3.0}, \text{ for } Q \leq 100\ m^3/s \qquad (C4\text{-}6b)$$

was fitted by eye.

Using Eq. C4-6 with daily streamflow values gives an estimate of suspended sand production. Figure C4-14 shows the predicted annual suspended sand produced by storms as a function of annual storm flow. The dashed line represents Eq. C4-2, which predicts the total annual suspended sediment produced by storms. The solid line on Fig. C4-14

Table C4-4
Santa Clara River (11114000) Actual vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)				ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)					
	1	2	3	4	5	6	7	8	5+7	6+8
WATER YEAR**	ACTUAL BASEFLOW	NATURAL BASEFLOW	TOTAL ACT FLOW	TOTAL NAT FLOW*	BASEFLOW ACT SED	BASEFLOW NAT SED*	STORM ACT SED	STORM NAT SED*	TOTAL ACT SED	TOTAL NAT SED*
1928 A	16.44	16.44	19.37	19.37	13862.89	13862.89	7521.73	7521.73	21384.61	21384.61
1929 A	24.53	30.30	36.26	42.04	20686.56	25554.44	57235.71	57237.02	77922.25	82791.44
1930 A	13.28	22.43	19.12	28.27	11200.27	18918.13	20631.83	20633.88	31832.10	39552.00
1931 A	13.63	22.47	19.49	28.33	11492.37	18950.17	20753.95	20752.86	32246.31	39703.02
1932 A	55.34	67.18	164.05	175.89	46667.86	56648.98	1481015.00	1481022.00	1527682.00	1537670.00
1933 P	18.07	30.44	29.91	42.28	15235.68	25668.27	57994.32	57994.23	73230.00	83667.50
1934 P	35.45	45.27	67.76	77.58	29894.09	38173.55	251453.13	251457.69	281347.19	289631.19
1935 P	39.83	63.04	126.86	150.07	33588.18	53156.28	1070041.00	1070045.00	1103629.00	1123201.00
1936 P	28.45	44.37	59.05	74.97	23986.84	37412.95	232314.06	232302.94	256300.88	269715.88
1937 P	58.63	83.47	334.86	359.70	49441.88	70387.06	5785853.00	5785904.00	5835334.00	5856291.00
1938 P	75.17	92.01	582.44	599.28	63385.07	77585.00	14064437.00	14064419.00	14127822.00	14142004.00
1939 P	35.11	51.81	82.30	99.01	29603.11	43691.73	437572.06	437576.25	467175.13	481267.94
1940 P	15.36	36.07	33.27	53.98	12950.18	30414.04	106231.44	106236.81	119181.56	136650.81
1941 P	98.31	98.79	1084.00	1084.49	82895.25	83307.19	37128560.00	37128496.00	37211440.00	37211792.00
1942 P	47.66	47.66	84.89	84.89	40193.12	40193.12	309357.75	309357.75	349550.81	349550.81
1943 P	86.33	86.33	419.62	419.62	72799.56	72799.56	7612819.00	7612819.00	7685618.00	7685618.00
1944 P	83.41	85.82	405.44	407.86	70335.88	72370.38	7240073.00	7240092.00	7310408.00	7312462.00
1945 P	47.82	53.66	100.13	105.98	40320.19	45248.35	508634.13	508629.94	548954.31	553878.25
1946 P	35.32	56.59	96.77	118.04	29783.31	47717.37	643436.38	643436.38	673219.63	691153.69
1947 P	19.32	47.39	55.95	84.02	16288.98	39960.38	302146.00	302147.75	318434.94	342108.13
1948 P	0.0	8.99	0.0	8.99	0.0	7579.05	0.0	0.0	0.0	7579.05
1949 P	1.94	8.76	2.70	9.53	1632.35	7388.48	1063.57	1063.17	2695.92	8451.65
1950 D	2.62	14.58	6.72	18.68	1973.35	12291.09	11601.13	11597.00	13574.48	23888.09
1951 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952 D	14.70	45.99	236.77	268.12	14654.00	38779.91	2583602.00	2584599.00	2598256.00	2623378.00
1953 D	4.08	31.03	4.08	31.03	3916.35	26169.06	0.0	0.08	3916.35	26169.14
1954 D	7.23	31.81	15.26	39.84	6129.95	26824.10	23833.04	23838.68	29962.99	50662.78
1955 D	1.17	16.03	1.17	16.03	998.47	13517.93	0.0	0.00	998.47	13517.93
1956 D	1.53	22.70	17.50	41.89	2050.25	19141.24	103926.81	135981.81	105977.06	155123.00
1957 D	2.41	18.54	6.93	23.68	2975.02	15635.55	16492.13	19882.69	19467.15	35518.24
1958 D	8.96	84.30	343.56	516.04	8942.00	71089.31	4433950.00	6435269.00	4442892.00	6506358.00
1959 D	2.42	43.22	23.83	73.43	2655.00	36444.98	140055.44	231560.19	142710.44	268005.13
1960 D	0.41	17.32	0.41	17.32	112.10	14601.13	0.0	0.02	112.10	14601.16
1961 D	0.57	7.34	0.57	7.34	349.52	6192.85	0.0	0.0	349.52	6192.85
1962 D	4.35	55.12	276.87	411.72	3789.00	46482.01	7385808.00	10940663.00	7389597.00	10987145.00
1963 D	1.75	24.36	7.67	31.57	1424.92	20543.80	36090.15	48098.74	37515.07	68642.50
1964 D	2.28	14.15	5.82	18.39	2435.92	11935.75	9457.60	12278.70	11893.52	24214.45
1965 D	0.45	20.47	9.36	30.90	118.71	17258.11	29480.39	37100.54	29599.10	54358.65
1966 D	3.30	63.58	190.08	304.13	3300.00	53609.35	3656336.00	5291804.00	3659636.00	5345413.00
1967 D	13.19	110.76	140.89	294.06	12954.00	93400.06	1195667.00	2027556.00	1208621.00	2120956.00
1968 U	2.79	59.13	12.07	71.60	2774.50	49858.02	65897.00	101667.50	68671.50	151525.50
1969 U	11.99	130.34	1097.16	1274.35	3520.00	84613.06	45800784.00	51381248.00	45804304.00	51465856.00
1970 U	10.18	72.53	64.31	138.58	4419.25	61157.88	598152.00	799986.38	602571.25	861144.25
1971 U	12.14	86.10	82.25	181.44	13640.00	72599.69	2173715.00	3405770.00	2187355.00	3478369.00
1972 U	5.99	38.57	36.65	84.12	6442.50	32524.17	425424.00	758570.31	431866.50	791094.44
1973 U	7.52	75.60	247.67	349.75	5458.00	63747.05	3906976.00	4740899.00	3912434.00	4804646.00
1974 U	4.95	74.25	77.22	165.15	3124.19	62611.63	444533.00	621457.88	447657.19	684069.50
1975 U	2.80	68.61	63.42	149.79	1268.00	57857.93	485056.00	743206.38	486324.00	801064.25
1976 U	1.24	0.0	15.69	-1.00	3284.00	-1.00	58043.00	-1.00	61327.00	-1.00

*Negative one (-1.00) indicates data unavailable.
**See Table C4-5.

Table C4-5
Santa Clara River (11114000)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1928 A	0.02	0.02
1929 A	0.10	0.10
1930 A	0.13	0.14
1931 A	0.16	0.18
1932 A	1.69	1.72
1933 P	1.76	1.80
1934 P	2.05	2.09
1935 P	3.15	3.22
1936 P	3.41	3.49
1937 P	9.24	9.34
1938 P	23.37	23.49
1939 P	23.84	23.97
1940 P	23.95	24.10
1941 P	61.17	61.32
1942 P	61.52	61.66
1943 P	69.20	69.35
1944 P	76.51	76.66
1945 P	77.06	77.22
1946 P	77.73	77.91
1947 P	78.05	78.25
1948 P	78.05	78.26
1949 P	78.06	78.27
1950 D	78.07	78.29
1951 N	78.07	78.29
1952 D	80.67	80.91
1953 D	80.67	80.94
1954 D	80.70	80.99
1955 D	80.70	81.00
1956 D	80.81	81.16
1957 D	80.83	81.19
1958 D	85.27	87.70
1959 D	85.41	87.97
1960 D	85.41	87.98
1961 D	85.41	87.99
1962 D	92.80	98.98
1963 D	92.84	99.04
1964 D	92.85	99.07
1965 D	92.88	99.12
1966 D	96.54	104.47
1967 D	97.75	106.59
1968 U	97.82	106.74
1969 U	143.62	156.21
1970 U	144.23	159.07
1971 U	146.41	162.55
1972 U	146.84	163.34
1973 U	150.76	168.14
1974 U	151.20	168.83
1975 U	151.69	169.63

*Suspended sand plus washload.
**Actual based on: A-Annual Flows, D-Daily Flows, N-No Flows, P-Predicted Annual Flows, U-USGS Estimates

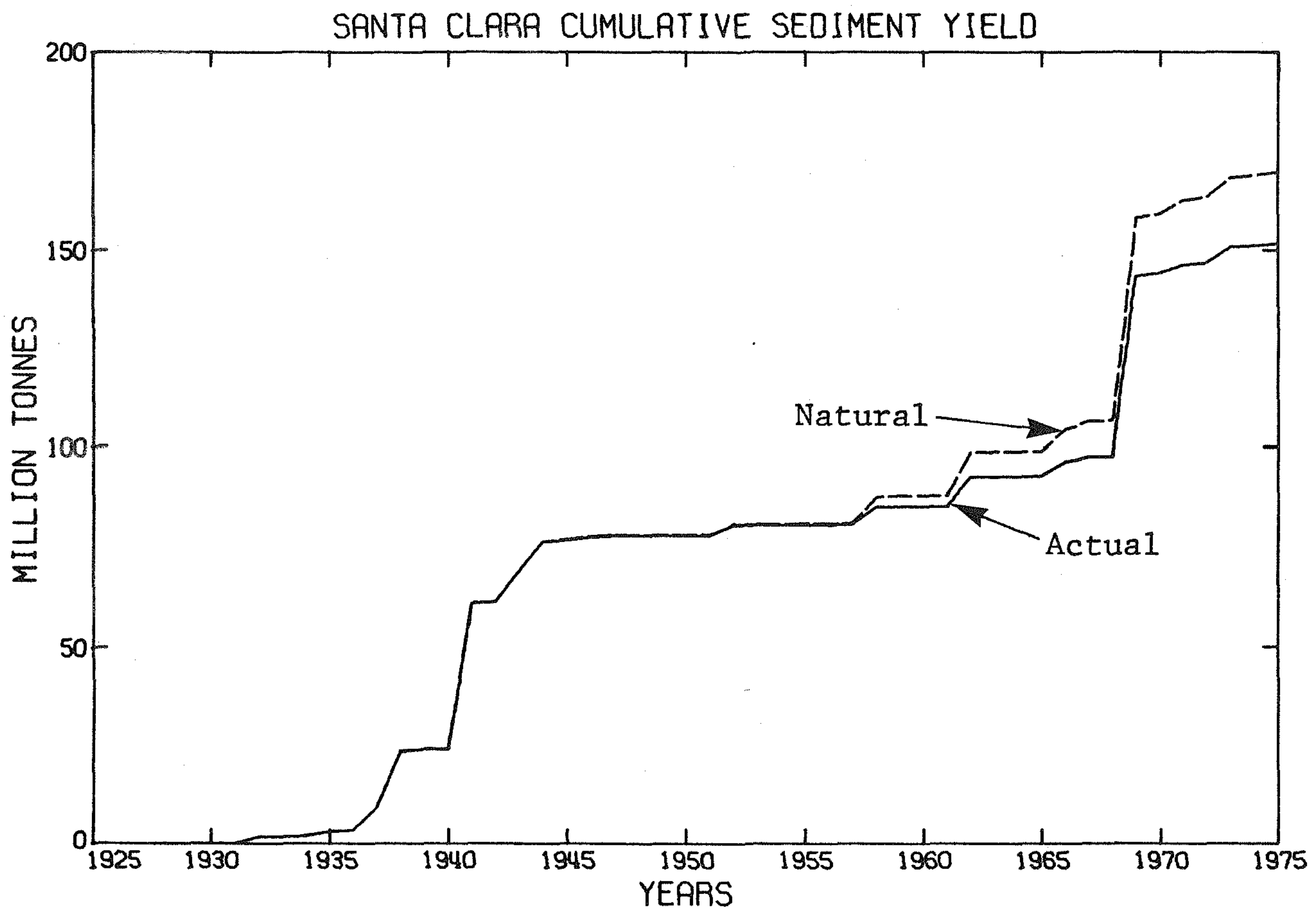

Figure C4-12 Calculated cumulative natural and actual suspended sediment yield at Santa Clara River station 11114000.

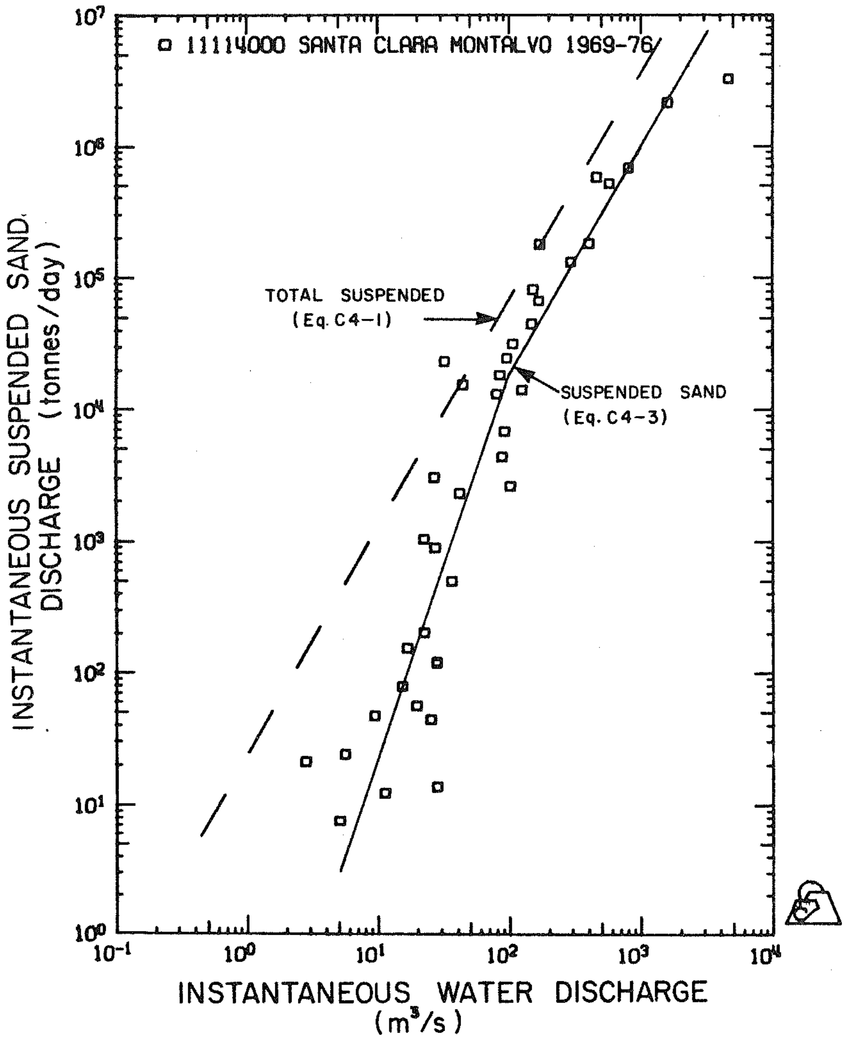

Figure C4-13 Relation of instantaneous suspended sand discharge at Santa Clara station 11114000, 1969-76.

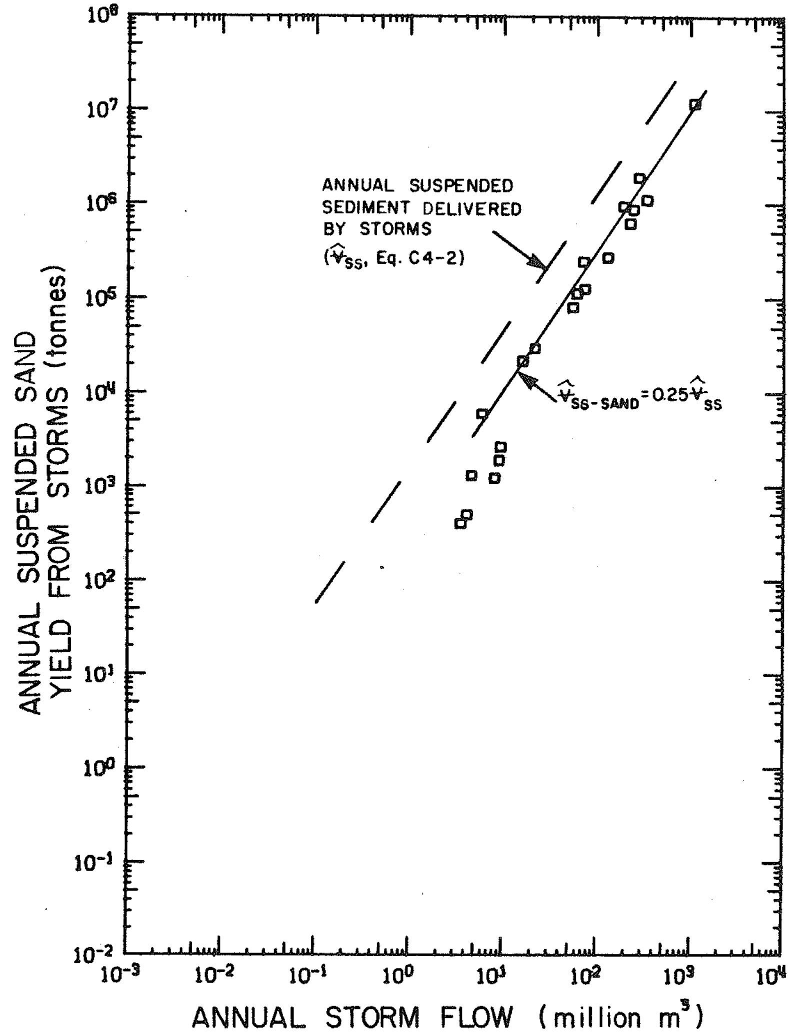

Figure C4-14 Relation of annual suspended sand yield produced by storms to annual storm flow at Santa Clara River station 11114000, 1950-76.

illustrates that for annual storm runoffs greater than 10 million m^3, the annual suspended sand yield approaches a constant fraction of the total suspended sediment yield (about 25 percent). This point is further illustrated in Tables C4-6 and C4-7. Table C4-6 gives annual suspended sediment yield and suspended sand yield (including base flows), and the ratio of the two, as percent sand. Table C4-7 presents the same data on a cumulative basis. In this case, for a given year, the percent sand column represents the cumulative suspended sand delivery as a percentage of the total cumulative suspended sediment delivery for the period 1950 to the given year. From these estimates, we can deduce that after only a few years, the cumulative percent sand in suspension fluctuated only slightly from year to year (between 24 and 26 percent).

C4.10 Bedload Discharge

The difficulties encountered in dealing with bedload discharge were mentioned in Section C3.10. The computerized version (Burkham et al., 1977) of the "modified Einstein" technique for estimating bedload, introduced in that section, has again been employed here. The bed sample required by the program was taken as the average of the samples shown in Fig. C4-4, excluding the sample, which was believed to be uncharacteristically coarse, marked by squares in the figure. The results are summarized in Table C4-8, and the computed bedload discharges have been plotted against water discharge in Figure C4-15. A curve, fitted the method of Section C18.1, is given by:

$$\hat{Q}_{sb} = 24.7\ Q^{1.27} \qquad \text{(C4-7)}$$

where $\hat{Q}_{sb}$ is predicted bedload discharge in tonnes/day. The correlation coefficient is 0.978 between log Q_{sb} and log Q. Using Eq. C4-7 with the daily discharges gives an approximation of annual bedload

Table C4-6
Santa Clara River at Montalvo (11114000)
Actual Total Sediment Yields, in tonnes

	1	2	3	4	5	6	7	8	9
	2+3			3/1		5/1	5/3	3+5	1+5
WATER YEAR	SUSP. YIELD,SY	SUSP. FINES	SUSP. SAND,SS	PERCENT SAND	BEDLOAD YIELD,BL	BL/SY (%)	BL/SS (%)	SAND AND COARSER	TOTAL YIELD
1950	13574.48	13064.50	509.98	3.76	3796.15	27.97	744.37	4306.13	17370.62
1951	0.00	0.0	0.00	100.00	0.0	0.0	0.0	0.0	0.0
1952	2598256.00	1969583.00	628672.31	24.20	240551.69	9.26	38.26	869224.00	2838807.00
1953	3916.35	3876.56	39.79	1.02	1756.96	44.86	4415.57	1796.75	5673.31
1954	29962.99	28685.12	1277.87	4.26	8458.88	28.23	661.95	9736.74	38421.87
1955	998.47	989.77	8.70	0.87	473.55	47.43	5445.58	482.24	1472.01
1956	105977.06	83993.63	21983.38	20.74	15186.68	14.33	69.08	37170.05	121163.69
1957	19467.14	18127.04	1340.10	6.88	4455.39	22.89	332.47	5795.49	23922.54
1958	4442892.00	3327133.00	1115759.00	25.11	377662.63	8.50	33.85	1493421.00	4820554.00
1959	142710.44	113025.25	29685.16	20.80	20212.39	14.16	68.09	49897.54	162922.81
1960	112.10	111.96	0.14	0.13	107.54	95.93	74681.88	107.69	219.64
1961	349.52	347.96	1.55	0.44	207.17	59.27	13323.15	208.73	556.69
1962	7389597.00	5448748.00	1940849.00	26.26	402411.94	5.45	20.73	2343260.00	7792008.00
1963	37515.07	31550.99	5964.07	15.90	5968.49	15.91	100.07	11932.56	43483.55
1964	11893.52	11463.77	429.75	3.61	3313.79	27.86	771.09	3743.54	15207.31
1965	29599.10	27692.73	1906.37	6.44	6393.14	21.60	335.36	8299.51	35992.25
1966	3659636.00	2705771.00	953864.44	26.06	248666.44	6.79	26.07	1202530.00	3908302.00
1967	632332.25	361639.00	270693.25	42.81	130341.13	20.61	48.15	401034.38	762673.38
1968	68671.50	66037.81	2633.67	3.84	7685.86	11.19	291.83	10319.54	76357.31
1969	45804304.00	33828336.00	11975956.00	26.15	1801185.00	3.93	15.04	13777141.00	47605488.00
1970	602571.25	522237.81	80333.44	13.33	52676.69	8.74	65.57	133010.13	655247.94
1971	2187355.00	1941899.00	245455.56	11.22	84654.00	3.87	34.49	330109.56	2272009.00
1973	3912434.00	3037571.00	874862.56	22.36	273438.50	6.99	31.26	1148301.00	4185872.00
1974	447657.19	321990.69	125666.50	28.07	67897.88	15.17	54.03	193564.38	515555.06
1975	486324.00	373249.94	113074.06	23.25	59136.76	12.16	52.30	172210.81	545460.75

Table C4-7

Santa Clara River at Montalvo (11114000)

Cumulative Actual Total Sediment Yields, in 10^6 Tonnes

	1	2	3	4	5	6	7	8	9
	2+3			3/1		5/1	5/3	3+5	1+5
WATER YEAR	SUSP. YIELD, SY	SUSP. FINES	SUSP. SAND, SS	PERCENT SAND	BEDLOAD YIELD, BL	BL/SY (%)	BL/SS (%)	SAND AND COARSER	TOTAL YIELD
1950	0.01	0.01	0.00	3.76	0.00	27.97	744.37	0.00	0.02
1951	0.01	0.01	0.00	3.76	0.00	27.97	744.37	0.00	0.02
1952	2.61	1.98	0.63	24.09	0.24	9.36	38.84	0.87	2.86
1953	2.62	1.99	0.63	24.06	0.25	9.41	39.11	0.88	2.86
1954	2.65	2.02	0.63	23.83	0.25	9.62	40.37	0.89	2.90
1955	2.65	2.02	0.63	23.82	0.26	9.64	40.45	0.89	2.90
1956	2.75	2.10	0.65	23.70	0.27	9.82	41.41	0.92	3.02
1957	2.77	2.12	0.65	23.59	0.27	9.91	42.01	0.93	3.05
1958	7.22	5.45	1.77	24.53	0.65	9.04	36.86	2.42	7.87
1959	7.36	5.56	1.80	24.45	0.67	9.14	37.38	2.47	8.03
1960	7.36	5.56	1.80	24.45	0.67	9.14	37.39	2.47	8.03
1961	7.36	5.56	1.80	24.45	0.67	9.14	37.40	2.47	8.03
1962	14.75	11.01	3.74	25.36	1.08	7.29	28.75	4.82	15.82
1963	14.79	11.04	3.75	25.34	1.08	7.31	28.86	4.83	15.87
1964	14.80	11.05	3.75	25.32	1.08	7.33	28.95	4.83	15.88
1965	14.83	11.08	3.75	25.28	1.09	7.36	29.10	4.84	15.92
1966	18.49	13.78	4.70	25.44	1.34	7.25	28.49	6.04	19.83
1967	19.12	14.15	4.97	26.01	1.47	7.69	29.56	6.44	20.59
1968	19.19	14.21	4.98	25.93	1.48	7.70	29.70	6.45	20.67
1969	64.99	48.04	16.95	26.08	3.28	5.05	19.34	20.23	68.27
1970	65.59	48.56	17.03	25.97	3.33	5.08	19.56	20.36	68.93
1971	67.78	50.50	17.28	25.49	3.42	5.04	19.77	20.69	71.20
1973	71.69	53.54	18.15	25.32	3.69	5.15	20.33	21.84	75.38
1974	72.14	53.86	18.28	25.34	3.76	5.21	20.56	22.04	75.90
1975	72.63	54.24	18.39	25.32	3.82	5.26	20.75	22.21	76.44

Table C4-8

Summary of Santa Clara River Total Sediment Load Calculations

		Observed				Calculated		
			Suspended Sediment Discharge (tonnes/day)					
Date	Time	Q Water Discharge (m^3/sec)	$Q_{ss\text{-}fine}$	$Q_{ss\text{-}sand}$	Q_{ss} Total Susp.	Q_{sb} Bedload Discharge (tonnes/day)	Q_s Total Sediment Discharge (tonnes/day)	$\frac{Q_{sb}}{Q_{ss}}$ (%)
Jan 20, 1969	305	454	539,000	199,000	739,000	56,200	795,000	7.6
Jan 25, 1969	1015	4,670	33,600,000	3,320,000	36,900,000	1,100,000	38,000,000	3.0
Jan 25, 1969	1725	1,510	7,250,000	2,040,000	9,300,000	203,000	9,500,000	2.2
Feb 19, 1969	1000	27.5	7,230	894	8,130	4,140	12,300	50.9
Dec 23, 1971	1000	9.32	1,110	46.4	1,160	145	1,310	12.5
Mar 3, 1973	1630	35.4	2,840	213	3,050	3,630	6,680	119.1

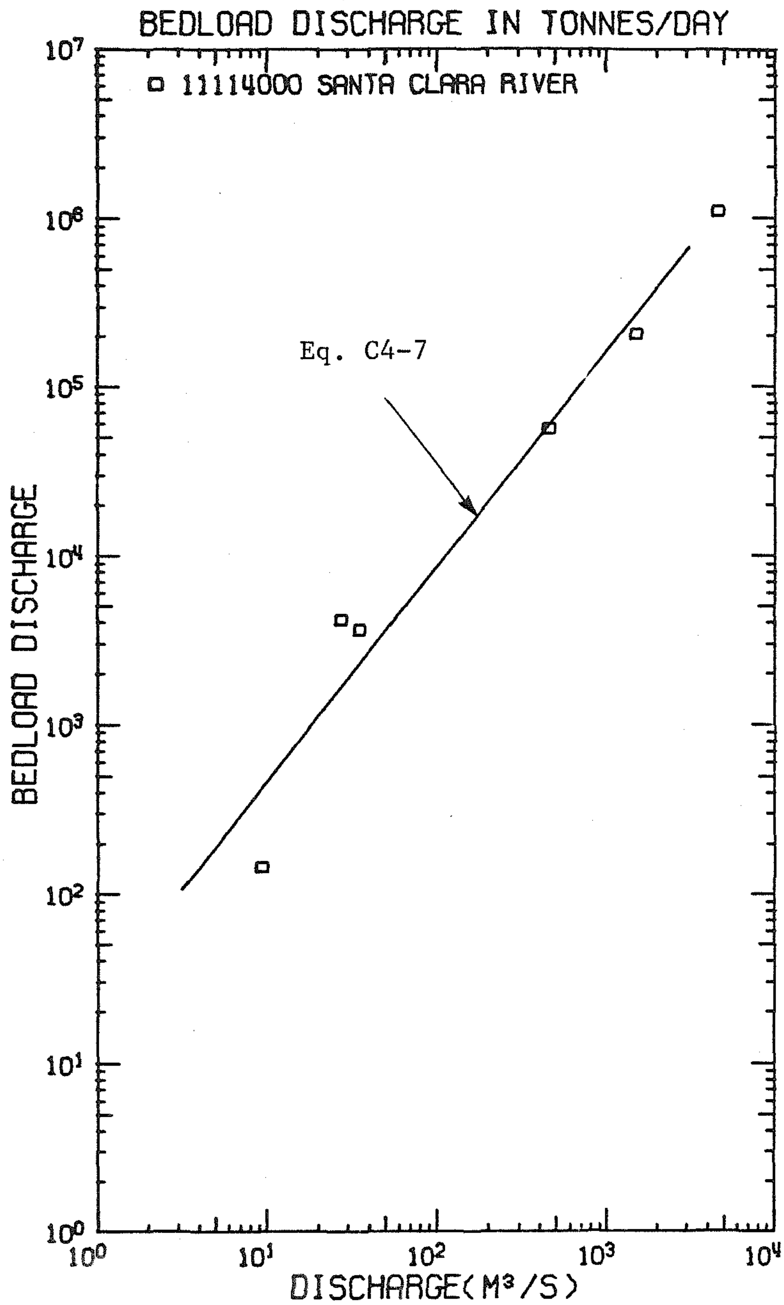

Figure C4-15 Santa Clara River calculated bedload discharge as a function of water discharge.

yields, listed in Table C4-6 and cumulatively in Table C4-7. The actual cumulative yields have been plotted in Fig. C4-16 by size class and mode of transport.

From Table C4-7 it can be seen that the 25-year average* ratio of bedload yield to suspended load yield is 5.26 percent for actual conditions. In forthcoming calculations of average sediment yields this ratio will be applied to estimate average bedload yield for natural conditions as well.

C4.11 Summary

The sediment yield calculations for the Santa Clara River are summarized in Table C4-9. For the total period of record (1928-1975), the table shows that the actual average annual yield of sand and coarser material has been about 0.96 million tonnes. Herron and Harris (1967, p. 653) estimated the average annual yield of littoral material by the Santa Clara River to be "on the order of 800,000 cubic yards [612,000 m^3]," based on sedimentation studies of delta deposits. Using a bulk density of 1.6 tonnes/m^3 this estimate converts to an average annual delivery of 0.98 million tonnes. For both the cases of the Ventura River and the Santa Clara River, the estimates of Herron and Harris are remarkably similar to those presented here.

A second comparison can be made between the reduction in sediment yield and the amount of sediment stored in Lake Piru (i.e., behind Santa Felicia Dam). A survey of Lake Piru in 1975 (USGS, 1962, 1977) revealed that 12.6 million m^3 (10,200 acre-feet) of material had accumulated in 20 years. Assuming a dry density of 1.04 tonnes/m^3 (65 lb/ft^3) this volume of material represents an annual accumulation of 0.655 million tonnes. For the same period, from Table C4-9,

*Note that the 1972 water year is missing from both Tables C4-6 and C4-7 due to the unavailability of annual flow data on magnetic tape.

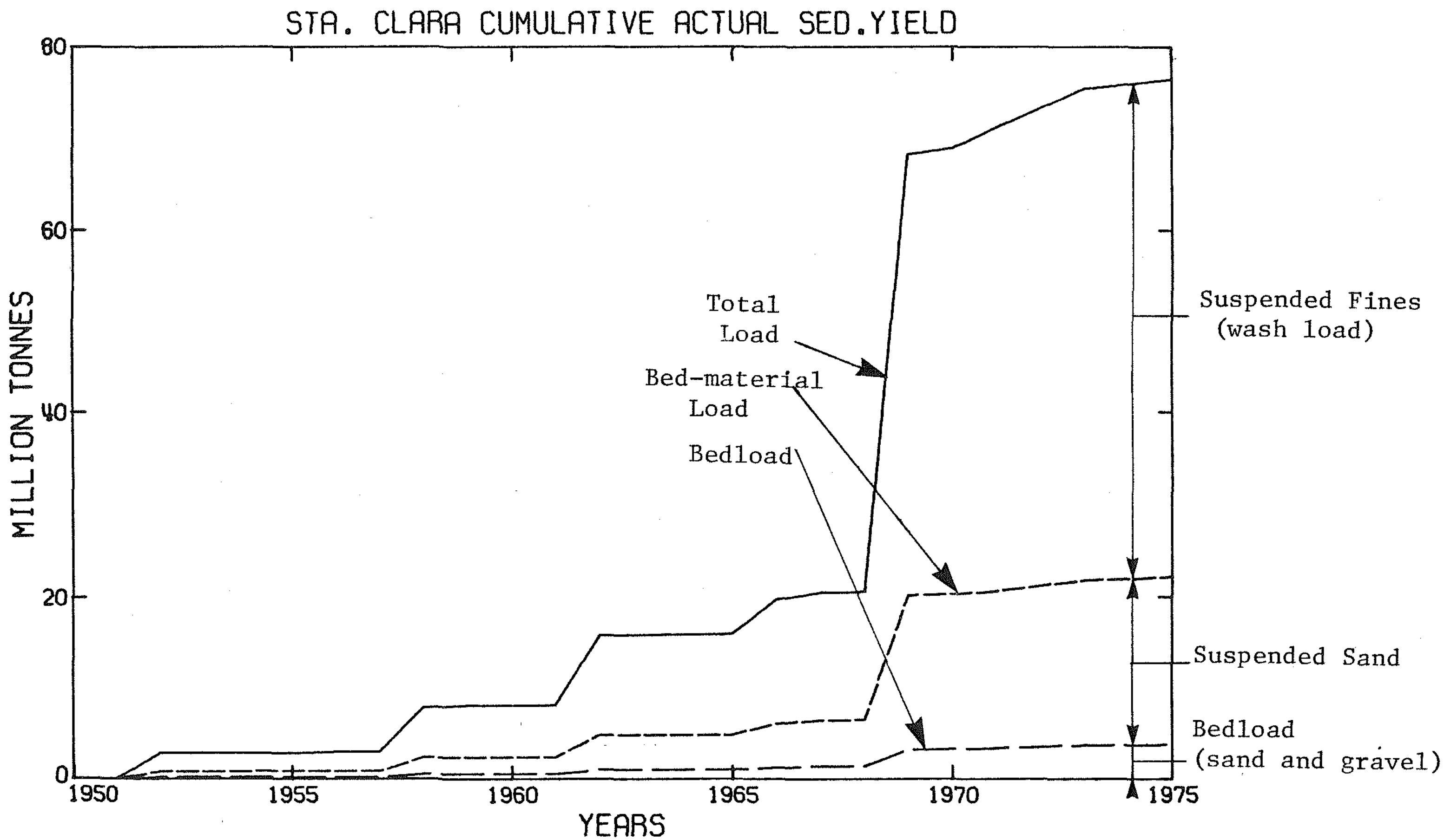

Figure C4-16 Santa Clara River cumulative sediment yield by mode of transport and size class.

the annual reduction of sediment yield by the river was estimated at 0.927 million tonnes. These figures suggest that 71 percent of the sediment reduction has been stored in Lake Piru. The remainder could possibly be explained by storage of material in Castaic Lake and Pyramid Lake, channel storage, and diversion of sediment at Saticoy.

Table C4-9 shows that the average annual reduction of sand and gravel yield for water years 1956 through 1975 has been about 270,000 tonnes. Assuming a dry bulk density of 1.6 tonnes/m^3 for beach material, this represents an annual deficit of 170,000 m^3 of beach material.

Table C4-9

Santa Clara River Average Annual Sediment Yield

Mode of Transport and Sediment Size Class	Annual Sediment Yield in Million Tonnes: Total Period of Record 1928 - 1975		Period of Maximum Control 1956 - 1975		Largest Event 1969 Water Year	
	Actual	Natural	Actual	Natural	Actual	Natural
Total Suspended Load	3.16	3.53	3.55	4.43	45.8	51.5
Suspended Fines (wash load)	2.37	2.65	2.65	3.31	33.8	38.0
Suspended Sand	0.790	0.883	0.901	1.12	12.0	13.5
Estimated Bedload (sand and gravel)	0.166	0.186	0.181	0.225	1.80	2.02
Total Sand and Gravel (bed-material load)	0.956	1.07	1.08	1.35	13.8	15.5
Total Sediment Load	3.33	3.72	3.73	4.66	47.6	53.5
Actual Sand Yield / Natural Sand Yield (%)	89%		80%		89%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C5 Calleguas Creek

C5.1 Drainage Basin Description

The Calleguas Creek drainage basin lies in the northern portion of the study area (see index map, Fig. C5-1). The basin is bounded on the north by the Santa Clara River drainage basin. Calleguas Creek is formed at the junction of Conejo Creek, which drains the Simi Hills area, and Arroyo Las Pasas, which drains the Oak Ridge and Santa Susana Mountains area (Fig. C5-1). The total area of the Calleguas Creek basin is 837 km^2, of which 21 percent is urbanized and 42 percent is agriculturally developed. The basin has the highest percentage of argicultural land use of the eight moderately developed basins discussed in this report.

Elevations within the basin range up to 645 meters, with the average elevation in the basin being from 300 to 370 m. Average annual rainfall (1936-1974) ranges from 45 cm in the easternmost area of the basin to 30 cm near the mouth of the river. The vegetation within the basin is mainly oak forest, with coastal sagebrush in the lower reach of the river. A large coastal salt marsh, Mugu Lagoon, lies at the mouth of the river.

C5.2 Geologic Setting

The Calleguas Creek basin lies on the southern half of the Oxnard plain, an alluvial plain located on a structural geologic depression known as the Ventura basin.* The Ventura basin is rimmed by Tertiary volcanics overlain by Miocene marine and Plio-Pleistocene nonmarine sedimentary rocks. The Tertiary volcanic formations are the most resistant, forming most of the ridges in the drainage basin.

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*Ventura basin is not to be confused with Ventura River basin. Ventura basin is a large subsurface geologically-defined depression, while the Ventura River basin is a hydrologic unit defined by tributaries that empty into the Ventura River.

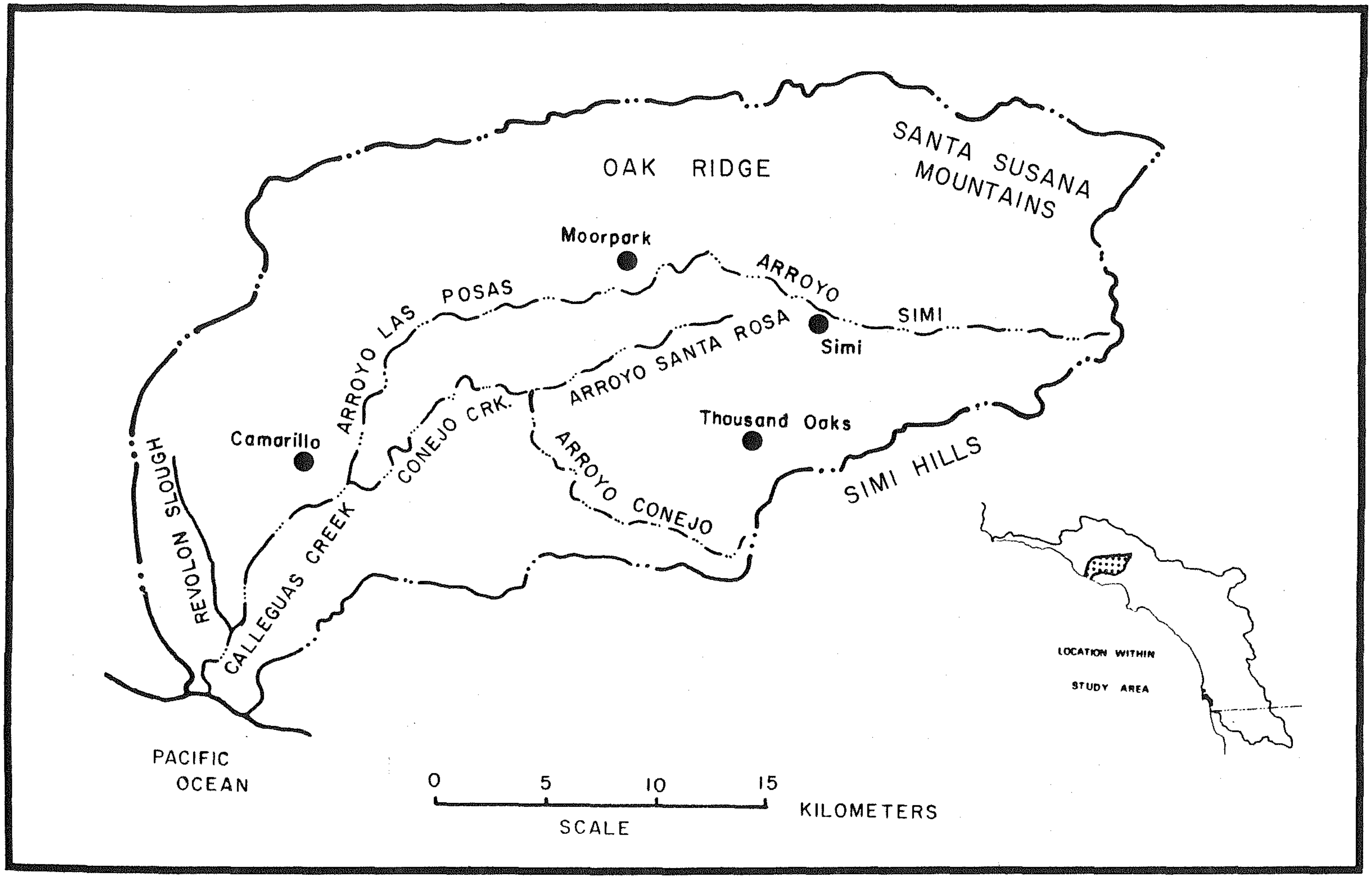

Figure C5-1 Calleguas Creek basin.

All of the faulting and folding in the basin is confined to the Pliocene and pre-Pliocene rocks that rim the structural basin. Fold axes as well as fault traces trend in an east-west direction, in keeping with the structural grain of the Transverse Ranges province, in which the Calleguas Creek basin is located.

C5.3 Control Facilities

The Calleguas Creek basin is the only basin of the eight discussed in which there are no large control structures on the stream. There is, however, considerable pumping of water from wells for irrigation.

C5.4 Gaging Stations on the Calleguas Creek Basin

Gaging station locations within the basin are shown in Fig. C5-2 and listed in Table C5-1. The stations have been tabulated and illustrated according to their record length. Twelve of the thirty-two stations are maximum discharge stations with record lengths of less than 15 years.

C5.5 Stream Bed Characteristics

For Calleguas and Conejo creeks, the bed elevation is plotted against the distance from the coast in Fig. C5-3. The average slope in the lower 55 km of Calleguas Creek stream bed is 5.79 m/km. The local slope at sediment stations 11105850 and 11106550 are 8.11 m/km and 5.36 m/km, respectively. As seen from Fig. C5-3, the average slope in the lower 40 km of Conejo Creek (10.68 m/km) is much steeper than the main channel of Calleguas Creek.

The sediment station farthest downstream (11106550) is located approximately 15 km upstream from the mouth of the creek. A grain-size distribution plot of each of the six composite bed sediment samples collected by the USGS at the station during the period from diverted by O'Neill Ditch, and $[\forall_V - P]$ is the natural flow from the area above Vail Dam, $\forall_V$, corrected for percolation losses, P, between the dam and Ysidora. $\forall_V$ is the total annual runoff reaching Vail Dam, as recorded at the gaging station (11042500) at the dam.

To estimate P, it was assumed that the rate of percolation between two stations in the central part of the reach is representative of the percolation along the entire reach. A nonlinear regression (see Section C18.3) was performed on the annual flows at the two stations, 11044500, near Fallbrook, and 11044000, near Temecula (E and F, respectively, on Fig. C6-2). To account for local inflows, the upstream station (11044000) flows were scaled by 1.21, which is the ratio of the uncontrolled drainage areas (i.e., not including the area above Vail Lake) of the two stations. The resulting correlation (Fig. C6-9) is given by

$$\hat{\forall}_F = 1.5\ (1.21\ \forall_T)^{0.93} - 3.2 \qquad \text{(C6-4)}$$

where $\hat{\forall}_F$ is the predicted annual flow near Fallbrook and $\forall_T$ is the annual flow near Temecula. By scaling Eq. C6-4 by 4, which is the ratio of the distance between Vail Lake and Ysidora (56 km) and between Temecula and Fallbrook (14 km), an equation can be found that gives P directly:

$$P = 4(\forall_v - 1.5\ \forall_v^{0.93} + 3.2) \qquad \text{(C6-5)}$$

In the diversion record on the O'Neill Ditch, seven years of discharge data are missing (1961-1967). For the first five of these years, there was no flow at Ysidora, thus we are assuming that there was no diversion during these years. For the last two years, in which there was actual flow at Ysidora, an unavoidable error was introduced in the calculation of natural flows. Therefore, for the water years 1966 and 1967, the estimates of natural suspended sediment yield will tend to be conservative.

All of the faulting and folding in the basin is confined to the Pliocene and pre-Pliocene rocks that rim the structural basin. Fold axes as well as fault traces trend in an east-west direction, in keeping with the structural grain of the Transverse Ranges province, in which the Calleguas Creek basin is located.

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The sediment station farthest downstream (11106550) is located approximatel 15 km upstream from the mouth of the creek. A grain-size distribution plot of each of the six composite bed sediment samples collected by the USGS at the station during the period from January 20, 1969, to September 30, 1975, is shown in Fig. C5-4.

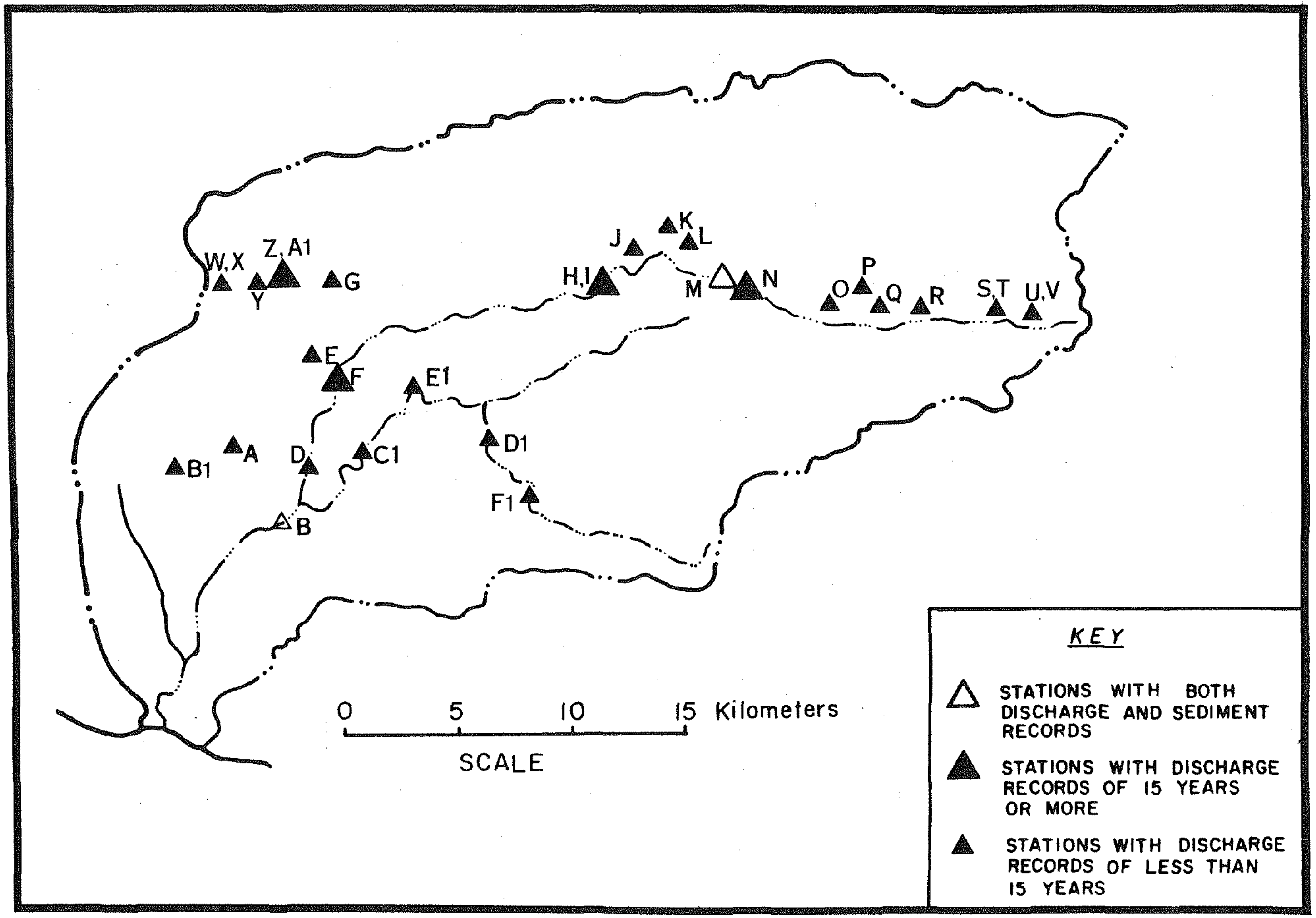

Figure C5-2 Location of streamflow and sediment gaging stations within Calleguas Creek basin.

Table C5-1
Gaging Stations within the Calleguas Creek Drainage Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG-MIN-SEC	LONGITUDE DEG-MIN-SEC	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	3R	Z4-1055		CAMARILLO HILLS DRAIN	34-13-30	119-03-48	VEN	8090	SD	1968			F	13.0		L
B*	1	Z4-1080	11-1065.50	CALLEGUAS C A CAMARILLO STA HOSP	34-10-46	119-02-20	VEN	5000	SD	1953		7	F	642.		F
C	3R	Z4-1095		LEWIS RD CYN	34-11-24	119-01-24	VEN	8090	SD	1968			F	4.40		L
D	1	Z4-1110	11-1060.00	CALLEGUAS C A CAMARILLO	34-13-00	119-00-54	VEN	5050	SD	1928	1958	23	F	427.		F
E	3R	Z4-1145		SOMIS DRAIN	34-13-36	119-01-30	VEN	8090	SD	1968			F	6.22		L
F*	1	Z4-1195	11-1059.90	CALLEGUAS C NR CAMARILLO	34-13-48	119-00-12	VEN	8090	SD	1955			G	438.		L
G	1	Z4-1210		FOX BARRANCA	34-17-06	119-01-24	VEN	8090	SD	1969			F	8.81		L
H	1	Z4-1300		CALLEGUAS C A MOORPARK	34-16-36	118-52-24	VEN	5999	SD	1934	1947		E			SF
I*	1	Z4-1380	11-1059.00	ARROYO SIMI A MOORPARK	34-16-36	118-52-24	VEN	8090	SD	1933		7	F	298.		L
J	3R	Z4-1395		HAPPY CAMP CYN	34-17-42	118-51-30	VEN	8090	SD	1968			F	30.8		L
K	3R	Z4-1405		STRATHEARN CYN	34-17-36	118-50-36	VEN	8090	SD	1968			F	10.6		L
L	3R	Z4-1420		NO 2 CYN	34-17-30	118-50-30	VEN	8090	SD	1968			F	13.5		L
M*	1	Z4-1480	11-1058.50	ARROYO SIMI NR SIMI	34-16-41	118-47-43	VEN	5000	SD	1933		2	F	183.		F
N	1	Z4-1600		CALLEGUAS C A SIMI	34-16-18	118-47-06	VEN	5999	SD	1934	1947		E			SF
O	3R	Z4-1640		ERRINGER RD DR	34-15-54	118-45-36	VEN	8090	SD	1968			F	3.63		L
P	3R	Z4-1650		DRY CYN	34-16-06	118-45-36	VEN	8090	SD	1968			F	10.6		L
Q	1	Z4-1680		ARROYO TAPO BL US 118	34-16-00	118-44-36	VEN	8090	SD	1969			F	49.2		L
R	1	Z4-1700		ARROYO SIMI A ROYAL AVE	34-15-54	118-44-06	VEN	8090	SD	1968			F	84.2		L
S	3R	Z4-1800		LAS LLAJAS CYN	34-16-18	118-42-00	VEN	8090	SD	1968			F	32.6		L
T	1	Z4-1810		LAS LLAJAS CYN	34-18-00	118-41-00	VEN	8090	SD	1968			F	17.6		L
U	3R	Z4-1850		WHITE OAK CYN	34-16-30	118-40-12	VEN	8090	SD	1968			F	4.40		L
V	3R	Z4-1865		HUMMINGBIRD C	34-16-30	118-39-42	VEN	8090	SD	1968			F	10.1		L
W	1	Z4-2045		LO MILLIGAN BARRANCA	34-15-42	119-04-00	VEN	8090	SD	1969			F	15.5		L
X	1	Z4-2050		MILLIGAN BARRANCA,M	34-16-18	119-03-48	VEN	8090	SD	1969			F	14.0		L
Y	1	Z4-2100		ARROYO COLORADO	34-16-48	119-03-30	VEN	8090	SD	1969			F	12.2		L
Z*	3X	Z4-2200	11-1070.00	HONDA BARRANCA NR SOMIS	34-16-06	119-02-54	VEN	5000	SD	1954	1973		G	6.66		F
A1	1	Z4-2203		HONDA BARRANCA	34-16-12	119-02-48	VEN	8090	SD	1969			F	6.99		L
B1	1	Z4-3200	11-1075.00	BEARDSLEY WA NR SOMIS	34-01-48	119-02-00	VEN	5000	SD	1954	1958		G	35.0		F
C1	1	Z4-4200	11-1065.00	CONEJO C NR CAMARILLO	34-12-36	118-59-36	VEN	5050	SD	1927	1931		F	181.		F
D1	1	Z4-4300		ARROYO CONEJO AB US 101	34-13-30	118-58-24	VEN	8090	SD	1968			F	202.		L
E1	1	Z4-4325	11-1064.00	CONEJO C AB HWY 101 NR CAMARILLO	34-14-10	118-57-50	VEN	5000	SD	1971			E	168.		F
F1	3R	Z4-4510		ARROYO CONEJO,SB	34-11-00	118-54-18	VEN	8090	SD	1968			F	34.7		L

*Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

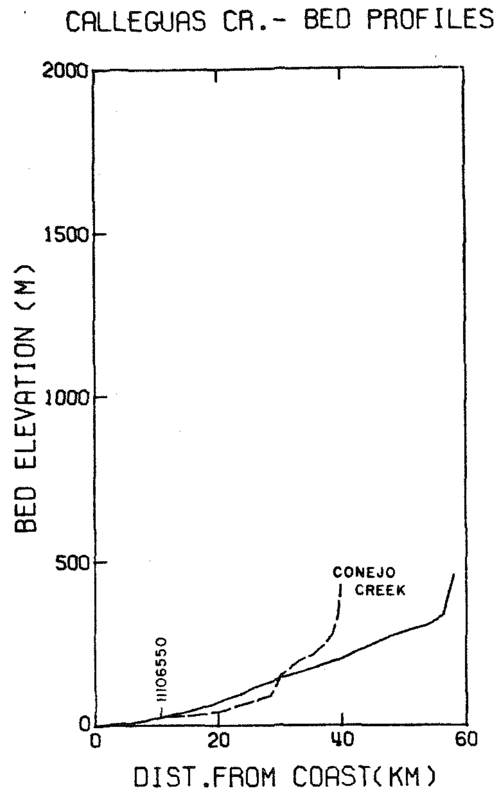

Figure C5-3 Bed profiles of main Calleguas Creek (solid line) and a tributary (dashed line).

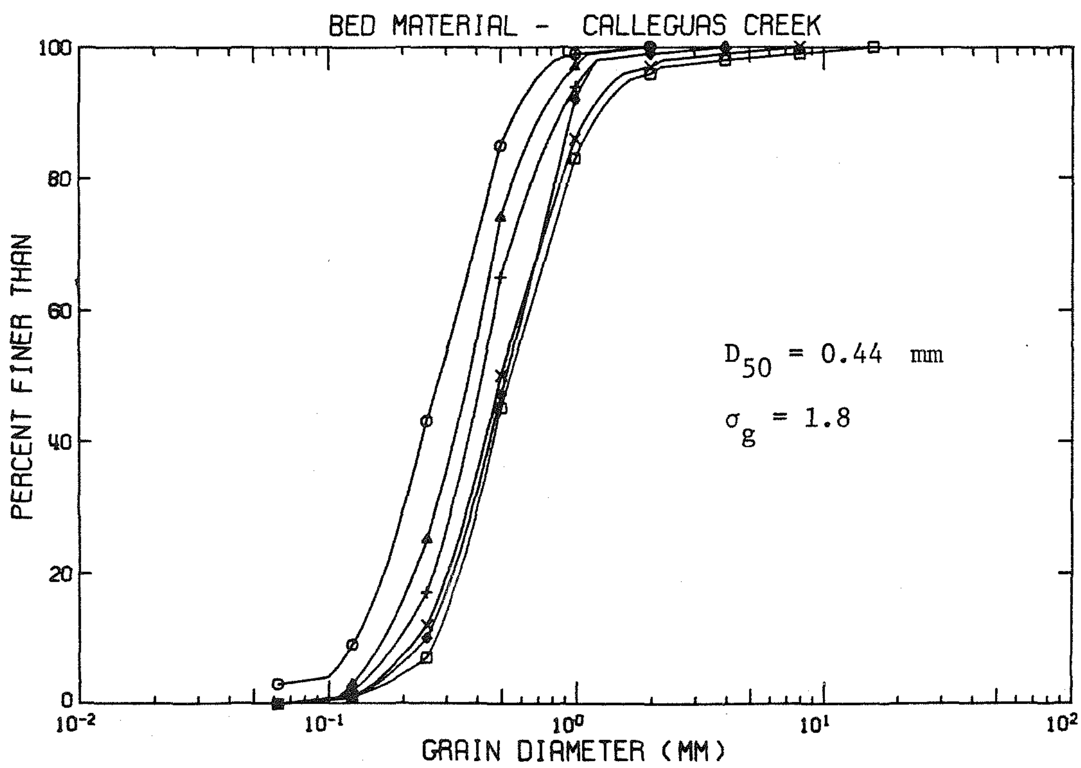

Figure C5-4 Composite bed-material samples collected at station 11106550 between January 20, 1969, and September 30, 1975.

January 20, 1969 to September 30, 1975 is shown in Fig. C5-4. The samples are composed largely of fine to coarse sand. The average median diameter of these samples is 0.44 mm with a geometric standard deviation of 1.8. The station is located on a natural stream bed that is bounded on both sides by 10 to 15 foot concrete, compacted dirt, or gravel levees, which were built in the late 1950s and early 1960s* by the United States Department of Agriculture, Soil Conservation Service. Figure C5-5 shows the configuration of the lower reach of the creek.

C5.6 Suspended Sediment Delivery

Calleguas Creek, unlike other rivers with moderately developed basins, has discharge records near the mouth for only a few years prior to 1969. Since no significantly long discharge record was available before 1969, some other statistical parameter for predicting sediment delivery was needed. Such a parameter ($\overline{Q}*$) was found by averaging Sespe Creek (11113001) and Arroyo Simi (11105850) annual water discharges, represented as percentages of their respective 1969 discharges. Sespe Creek was chosen because it has a large uncontrolled drainage area, comparable in size to Calleguas Creek. Arroyo Simi was selected because it is a tributary of Calleguas Creek and is a good natural predictor of flows in Calleguas Creek.

The curve relating annual suspended sediment (Q_{ss}) at Calleguas Creek station (11106550) to $\overline{Q}*$ is shown in Fig. C5-6 and is defined by

$$\hat{Q}_{ss} = 823\ \overline{Q}*^{1.83} \qquad (C5\text{-}1)$$

where $\hat{Q}_{ss}$ represents the predicted value of Q_{ss}. The correlation coefficent between log Q_{ss} and log $\overline{Q}*$ is 0.851. The curve fitting

*Bill Hayden, Ventura Flood Control District, personal communication.

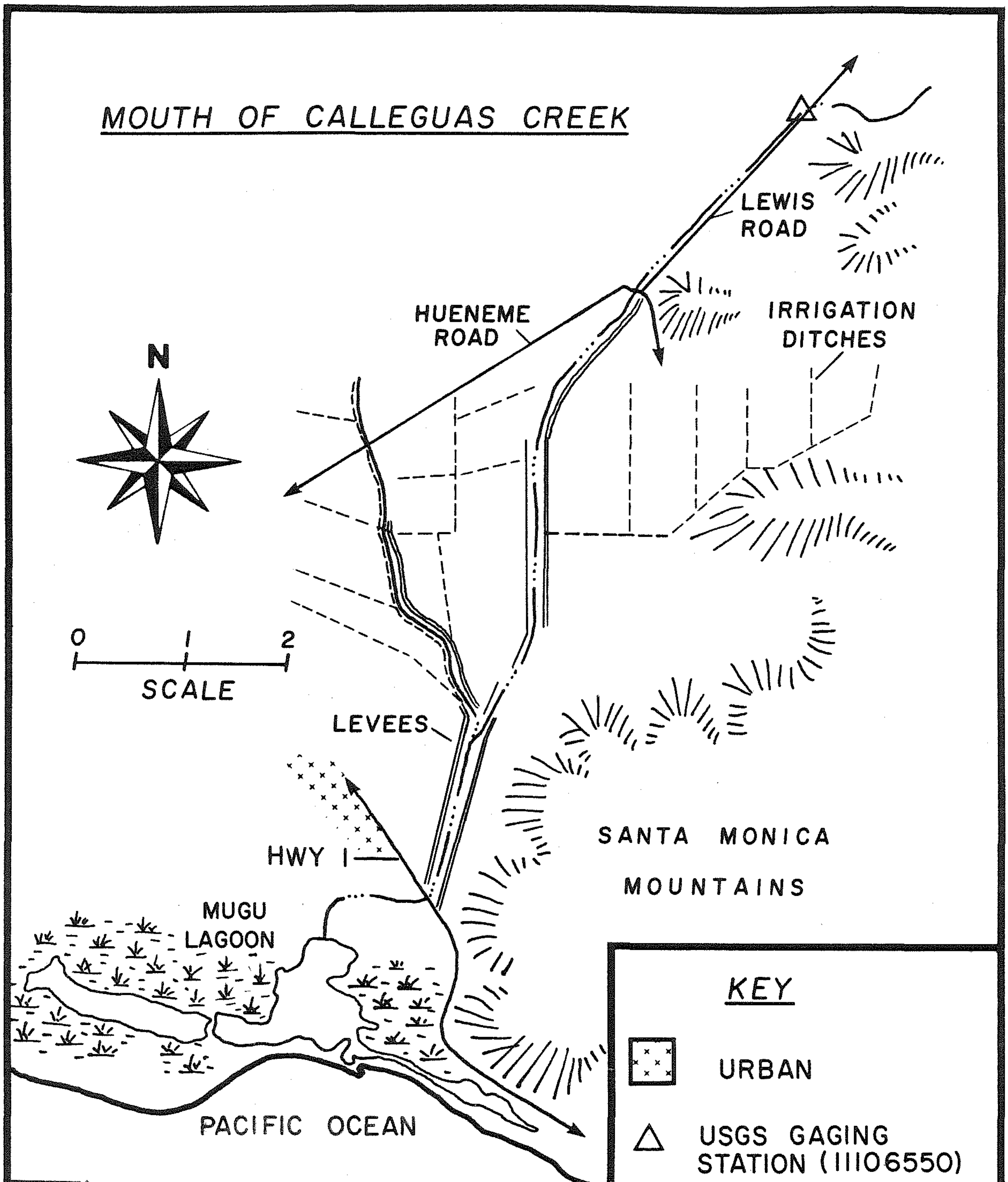

Figure C5-5 Lower reach of Calleguas Creek channel and floodplain.

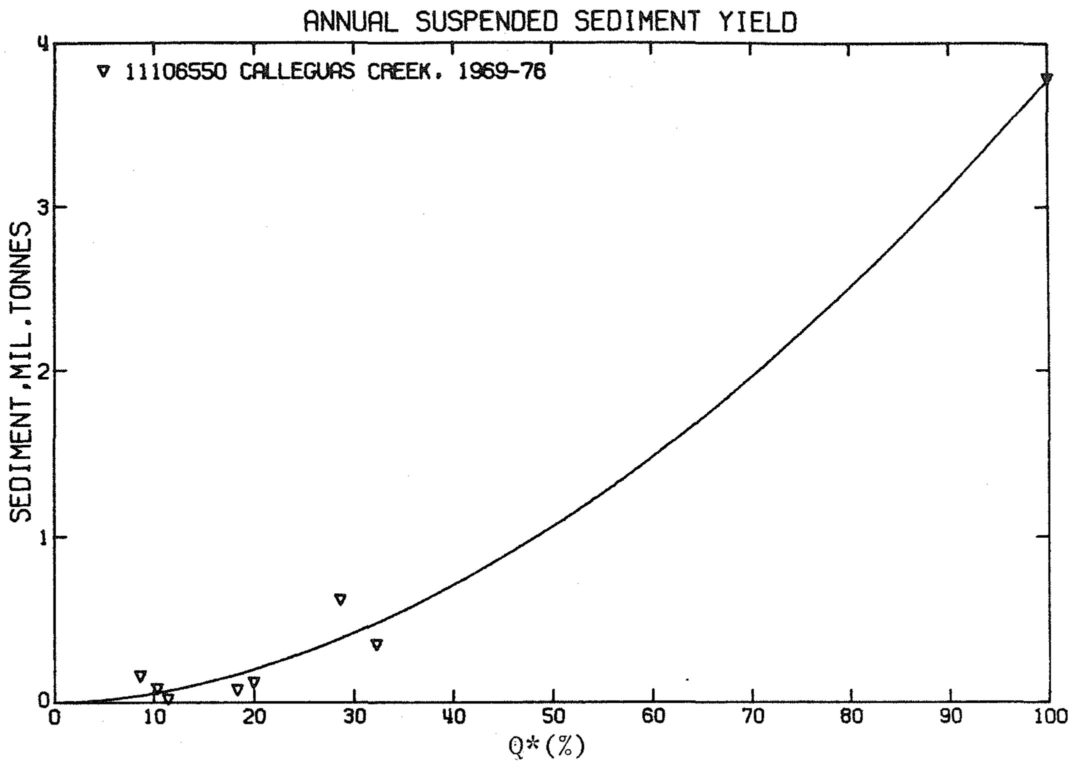

Figure C5-6 Calleguas Creek annual suspended sediment yield as a function of dimensionless discharge (see text).

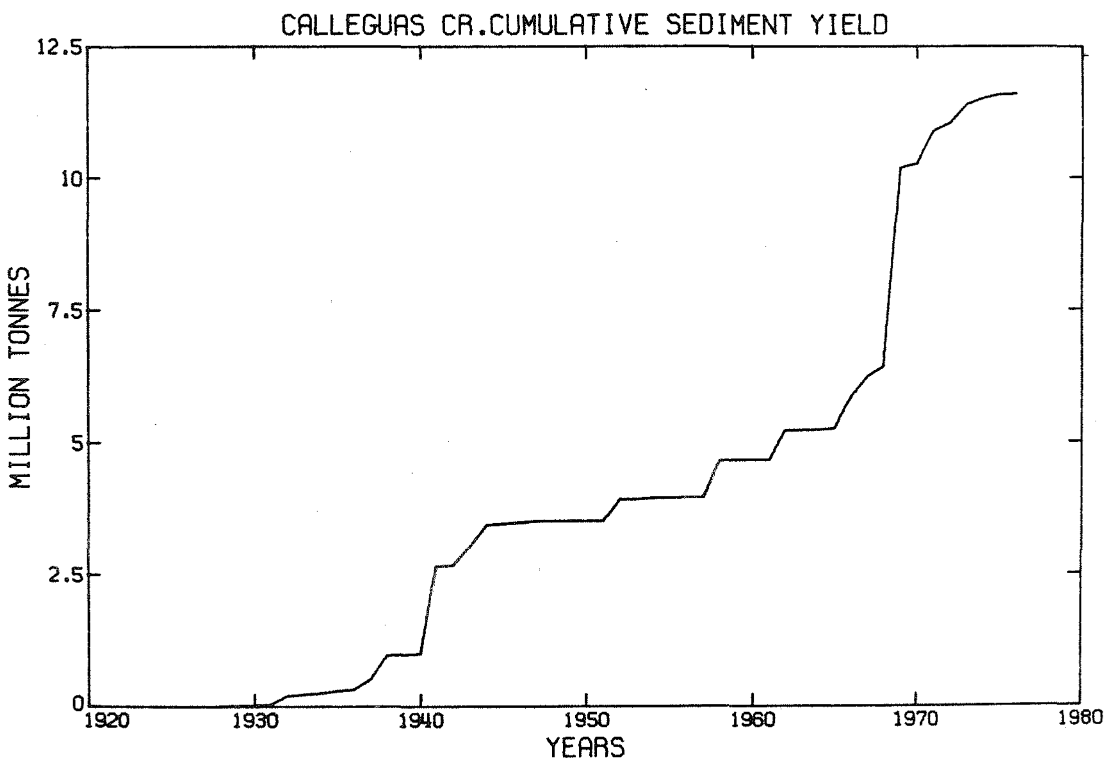

Figure C5-7 Calleguas Creek cumulative suspended sediment yield.

Table C5-2

SUSPENDED SEDIMENT YIELD OF CALLEGUAS CREEK(11106550), IN TONNES, RELATED TO Q*, THE AVERAGE OF THE DISCHARGES OF ARROYO SIMI(11105850) AND SESPE CREEK(11113001) REPRESENTED AS PERCENTAGES OF THEIR 1969 (MAXIMUM) DISCHARGES..................
* SUSPENDED SEDIMENT BASED ON: S-SESPE CREEK Q*, A-AVERAGE Q*, U-USGS ESTIMATES.

WATER YEAR*	11105850 Q*(%)	11113001 Q*(%)	AVERAGE Q*(%)	SEDIMENT YIELD	CUMUL. SEDIMENT
1928 S	-1.00	4.19	4.19	11342	11342
1929 S	-1.00	4.06	4.06	10711	22053
1930 S	-1.00	3.87	3.87	9796	31849
1931 S	-1.00	3.63	3.63	8728	40578
1932 S	-1.00	17.84	17.84	160758	201336
1933 S	-1.00	6.92	6.92	28407	229742
1934 A	0.94	11.18	6.06	22265	252008
1935 A	0.26	17.97	9.12	47042	299050
1936 A	0.0	11.33	5.67	19700	318751
1937 A	3.64	36.75	20.20	201795	520546
1938 A	10.54	51.36	30.95	440876	961422
1939 A	0.20	9.90	5.05	15948	977369
1940 A	0.05	6.98	3.52	8220	985590
1941 A	47.84	80.72	64.28	1679918	2665507
1942 A	0.0	9.08	4.54	13126	2678633
1943 A	19.68	36.64	28.16	370789	3049423
1944 A	27.84	30.75	29.30	398647	3448070
1945 A	0.25	11.70	5.98	21714	3469784
1946 A	0.37	13.85	7.11	29842	3499626
1947 A	1.85	9.74	5.80	20537	3520163
1948 A	0.0	1.71	0.86	619	3520782
1949 A	0.0	1.95	0.97	785	3521567
1950 A	0.0	3.63	1.82	2454	3524021
1951 A	0.0	0.76	0.38	139	3524160
1952 A	27.03	32.28	29.65	407599	3931758
1953 A	0.0	4.80	2.40	4087	3935845
1954 A	2.17	7.11	4.64	13678	3949523
1955 A	1.19	3.67	2.43	4175	3953698
1956 A	1.99	6.36	4.18	11265	3964964
1957 A	0.41	5.11	2.76	5287	3970251
1958 A	29.62	48.61	39.12	676765	4647016
1959 A	0.16	6.85	3.51	8181	4655197
1960 A	0.01	2.77	1.39	1505	4656702
1961 A	0.0	1.92	0.96	765	4657467
1962 A	32.32	38.47	35.40	563614	5221081
1963 A	2.07	3.55	2.81	5462	5226543
1964 A	2.39	2.94	2.67	4953	5231496
1965 A	6.27	5.68	5.98	21719	5253214
1966 A	38.86	33.89	36.38	592548	5845762
1967 A	24.00	33.76	28.88	388383	6234145
1968 A	33.03	5.22	19.12	182601	6416746
1969 U	100.00	100.00	100.00	3773300	10190046
1970 U	8.59	12.07	10.33	80382	10270428
1971 U	42.97	14.35	28.66	611820	10882248
1972 U	10.86	6.43	8.65	155950	11038198
1973 U	29.84	34.71	32.27	343000	11381198
1974 U	28.22	11.69	19.95	116992	11498190
1975 U	22.59	14.04	18.32	73500	11571690
1976 U	17.46	5.41	11.43	15554	11587244

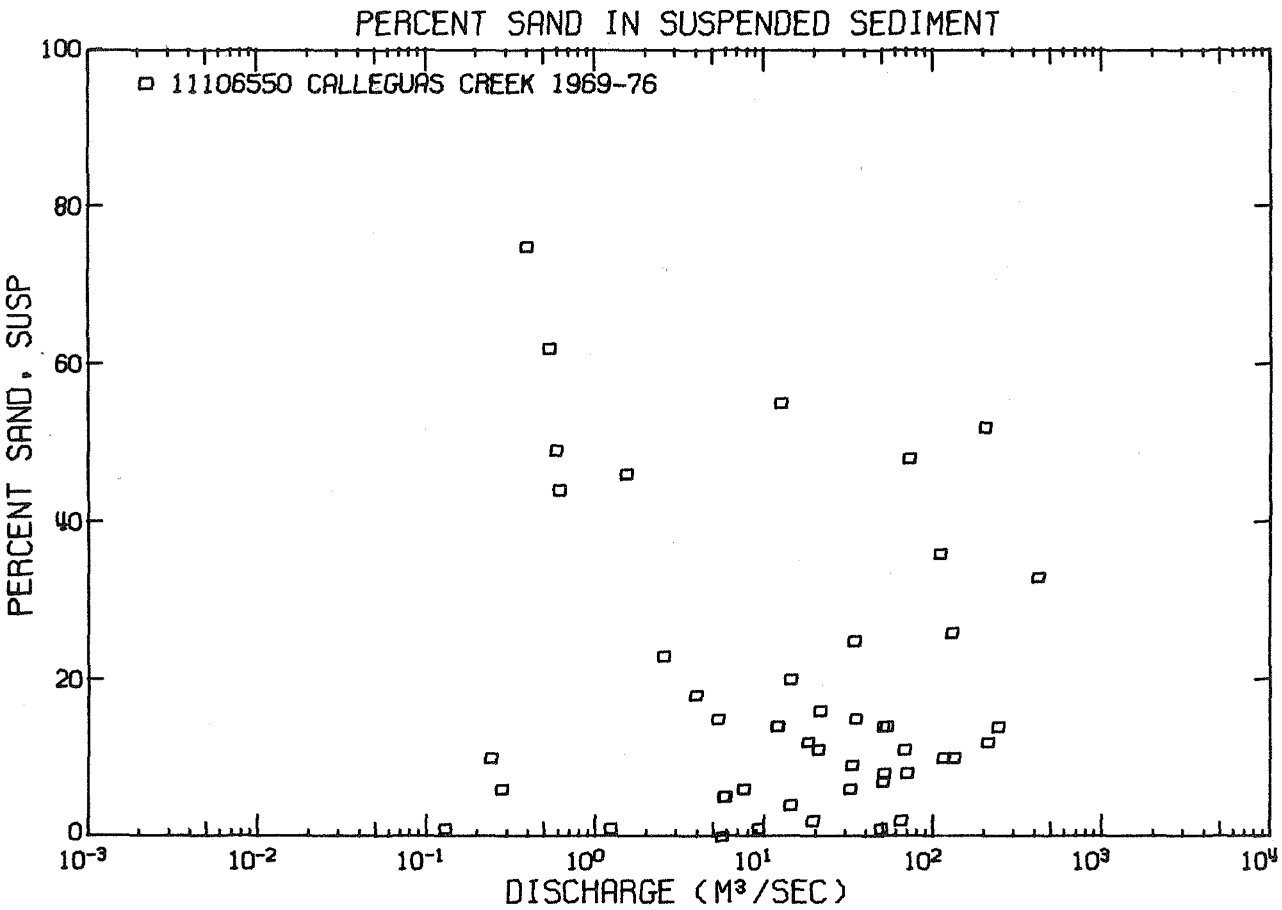

Figure C5-8 Percent sand in suspension for samples collected on Calleguas Creek (11106550), plotted as a function of discharge.

C5.8 Summary

The final sediment yield estimates are summarized in Table C5-3. The table shows that about 1.28 million tonnes of sand and gravel were delivered to the coast during the 1969 water year, roughly 16 times the estimated average annual delivery. Since Calleguas Creek discharges into Mugu Lagoon, which in turn is located at the head of Hueneme Canyon, it is not likely that much of the Calleguas Creek yield is useful for nourishment of nearby beaches.

Table C5-3

Calleguas Creek Average Annual Sediment Yield

Mode of Transport and Sediment Size Class	Annual Sediment Yield in Tonnes Total Period of Record 1928 - 76	Largest Event 1969 Water Year
Total Suspended Load	236,000	3,770,000
Suspended Fines (wash load)	180,000	2,870,000
Suspended Sand	56,800	906,000
Estimated Bedload (sand and gravel)	23,600	377,000
Total Sand and Gravel (bed-material load)	80,400	1,280,000
Total Sediment Load	260,000	4,150,000

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C6 Santa Margarita River Basin

C6.1 Drainage Basin Description

The Santa Margarita River basin is located in the south central portion of the study area (see index map, Fig. C6-1). The river basin is bounded on the south by the San Luis Rey River basin and partially on the north by the Lake Elsinore basin. The Santa Margarita River basin straddles the Riverside-San Diego county line, with the northeastern 75 percent of the basin in Riverside County. Of the 1927 km^2 drainage area contained within the basin, 26 percent is agriculturally developed and 5 percent is urbanized.

The Santa Margarita River basin varies greatly in elevation and rainfall and thus also in vegetal cover. The highest elevations are found at Thomas Mountain, at the southern drainage divide, where they range up to 2,000 m, and where the annual precipitation averages 50 cm. The only coniferous forest in the basin is found at Palomar Mountain. The narrow floodplain and lowland area east of Murrieta Creek are dominated by chaparral with a coastal salt marsh at the river mouth, where the annual precipitation averages about 20 cm. Intermediate elevations are also dominated by chaparral, with a small grassland near the headwaters of Murrieta Creek.

C6.2 Geologic Setting

The Santa Margarita River drains the portions of the Peninsular Ranges province in southern California, flowing across a terrain composed largely of crystalline rocks of the southern California batholith. These include igneous rocks of various granitic compositions and those that they intruded over 100 million years ago -- Mesozoic and Paleozoic meta-sedimentary and meta-volcanic rocks. The batholitic rocks are overlain to the west by younger marine sediments

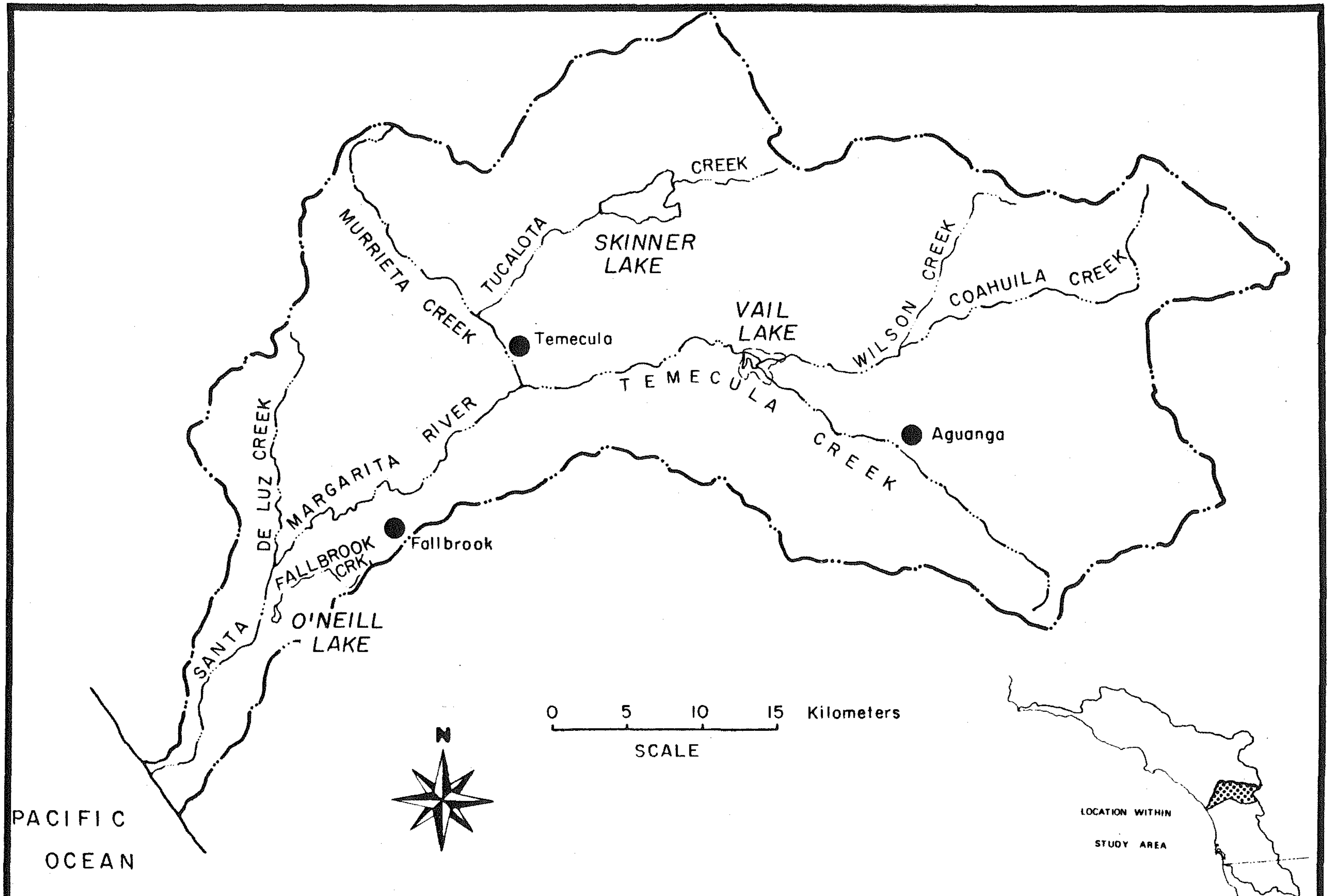

Figure C6-1 Santa Margarita River basin.

of Eocene and Miocene age. More recently, wave action cut several terraces in the older rocks along coastal reaches of the basin as the area emerged during Pleistocene time.

Outside of general uplift, tectonic activity has been confined mainly to the Elsinore fault zone. This zone has downdropped the regions adjacent to it and east of it, producing topographic contrast with the elevated terrain to the west; Murrieta Creek flows over the alluviated lowlands along the fault zone before turning west to join the Santa Margarita River.

C6.3 Control Facilities

There are three storage facilities and one major diversion canal on the Santa Margarita River basin. The capacities, completion dates, and drainage areas of these facilities are given in Table C6-1.

Vail Lake

Vail Lake is the largest impoundment facility on the Santa Margarita River basin, with a capacity of 60.9 million m^3. The lake, owned by Kaiser-Aetna, is located at the confluence of Wilson and Temecula creeks. The water is released, as required for mixed uses, down Temecula Creek for diversion about 1.6 km downstream. Although the dam was not complete until June 1949, no spill has occurred since November 13, 1948, the date of closure.

Lake Skinner (Robert A. Skinner Dam)

Lake Skinner is owned by the Metropolitan Water District of Southern California and has a capacity of 55.1 million m^3.* The reservoir is used for storage of state water and/or Colorado River water imported through the San Diego Canal. Filling began in April 1973. Current law requires that all local inflows, except

*Mike Young, MWDSC, personal communication, January 16, 1979.

Table C6-1

Control Structures of the Santa Margarita River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
O'Neill Lake	1.63	1883	31.1
Vail Lake	60.9	June 1949	826
Skinner Lake (Robert F. Skinner Dam)	55.1	April 1973	132

Diversion Facility	Completion Date	Diversion To/From
O'Neill Ditch	1883	The gravity canal diverts water from Santa Margarita River, 9.7 upstream of Ysidro gaging station, to O'Neill Lake. Water in O'Neill Lake was formerly used for irrigation in Santa Margarita Ranch; now is used by U.S. Navy.

NOTE: Total drainage area of the Santa Margarita River basin is 1927 km^2.

precipitation on the lake surface, be passed through the reservoir. Due to the youth of the facility and the operating policy, no consideration has been given to Lake Skinner in sediment calculations.

O'Neill Ditch and Lake O'Neill

Lake O'Neill and the O'Neill Ditch are operated by the Environmental Protection branch of the U.S. Marine Corps base at Camp Pendleton. The lake is supplied to some extent by local runoff, but primarily by diversions from the Santa Margarita River through the O'Neill Ditch. The O'Neill Ditch diverts water 9.7 km upstream from the gaging station at Ysidora (11046000). Records prior to 1961 are available in USGS Water-Supply Papers, and from 1968 to the present were supplied by the U.S. Marine Corps.

C6.4 Gaging Stations

Gaging station locations within the basin are shown in Fig. C6-2 and tabulated in Table C6-2 according to their length of record. Of the 24 stations within the basin, eleven have discharge records of 15 years or more, one of which being a maximum discharge, crest-stage station.

C6.5 Stream Bed Characteristics

The bed elevation of the Santa Margarita River is plotted against distance from the coast in Fig. C6-3. The channel has an even, gentle slope. The channel slope averages 1.90 m/km along the lower 40 km of the river and reaches a maximum of 5.27 m/km 70 to 90 km upstream from the coast. The sediment station (11046000) is located on a coastal lagoon 2.7 km upstream from the mouth, where the local slope is only 0.79 m/km. The surface bed material at the station, based on five composite USGS samples collected between November 27, 1967 and August 16, 1973, and one collected by Brownlie on November 23, 1978, has a mean diameter of 0.35 mm with a geometric standard deviation of 1.8 (Fig. C6-4).

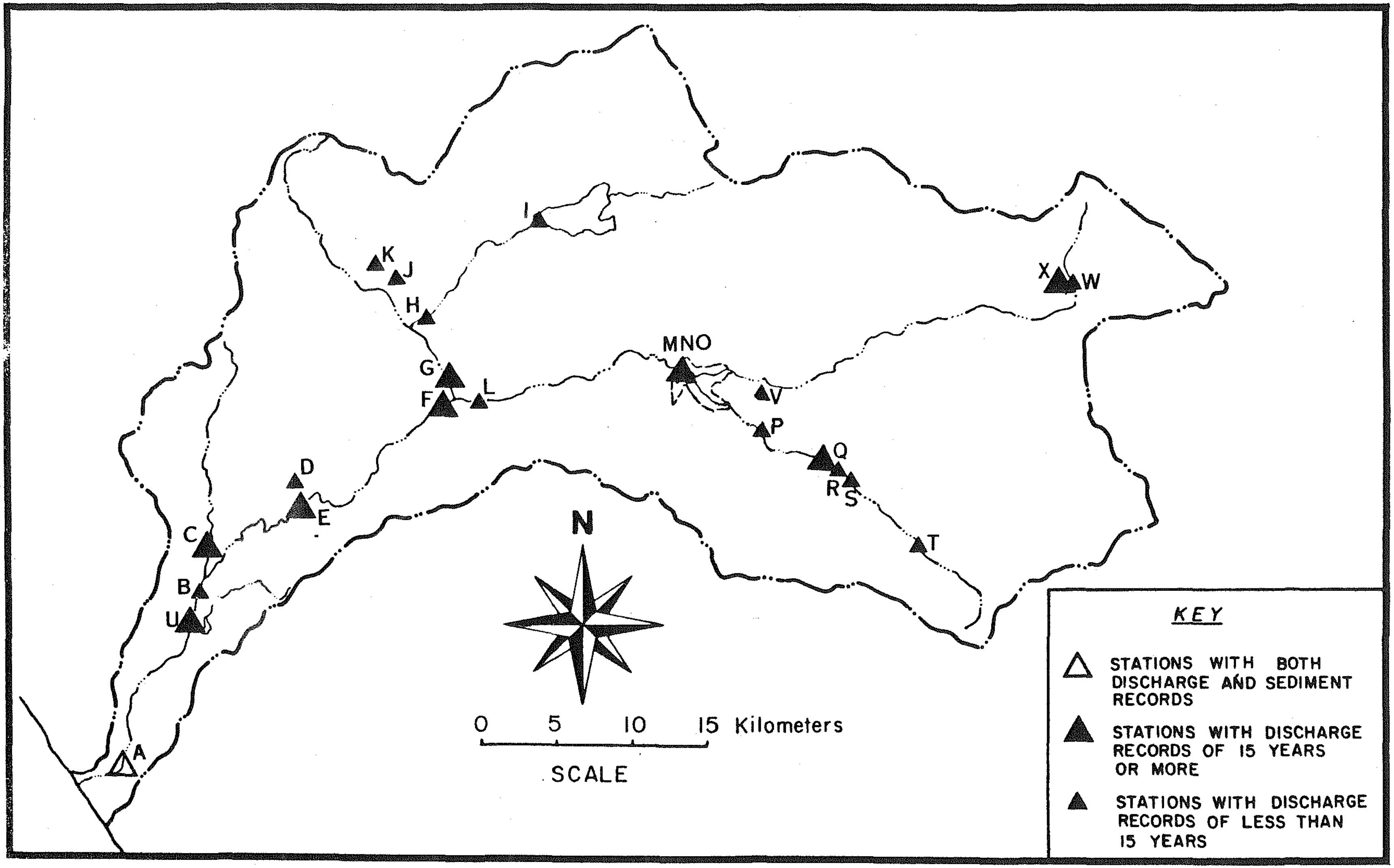

Figure C6-2 Location of streamflow and sediment gaging stations within the Santa Margarita River basin.

Table C6-2
Gaging Stations within the Santa Margarita River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG-MIN-SEC	LONGITUDE DEG-MIN-SEC	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A*	1	X2-1100	11-0460.00	SANTA MARGARITA R A YSIDORA	33-14-13	117-23-14	SDG	5000	SD	1923		1	G	1917.		F
B	1	X2-1175	11-0450.00	SANTA MARGARITA R NR DELUZ STA	33-21-12	117-19-30	SDG	5000	SD	1925	1926		G	1826.		F
C*	1	X2-1230	11-0449.00	DE LUZ C NR FALLBROOK	33-22-00	117-19-24	SDG	5000	SD	1951	1967		P	123.		F
D	1	X2-1340	11-0446.00	SANTA MARGARITA R TRIB NR FALLBRK	33-24-36	117-16-42	SDG	5000	SD	1961	1973		G	1.35		F
E*	1	X2-1350	11-0445.00	SANTA MARGARITA R NR FALLBROOK	33-23-54	117-15-42	SDG	5000	SD	1924			G	1668.		F
F*	1	X2-1425	11-0440.00	SANTA MARGARITA R NR TEMECULA	33-28-24	117-08-30	RIV	5000	SD	1923			G	1523.		F
G*	1	X2-1500	11-0430.00	MURRIETA C A TEMECULA	33-28-48	117-08-36	RIV	5000	SD	1924			G	575.		F
H	1	X2-1510	11-0429.00	SANTA GERTRUDIS C NR TEMECULA	33-31-24	117-10-00	RIV	5050	SD	1952	1954		G	228.		S
I	1	X2-1515		SKINNER LK NR MURRIETA HOT SPRING	33-34-59	117-04-12	RIV	4412	SD	1973			E	133.	451	S
J	1	X2-1520	11-0428.00	WARM SPRINGS C NR MURRIETA	33-31-54	117-10-30	RIV	5050	SD	1952	1954		G	150.		S
K	1	X2-1530	11-0426.50	COLE CYN C NR MURRIETA	33-33-42	117-14-06	RIV	5050	SD	1952	1954		G	23.3		S
L	5	X2-1600	11-0426.30	TEMECULA C NR TEMECULA	33-28-54	117-05-00	RIV	5000	SD	1905	1906		F	907.		F
M*	1	X2-1700	11-0425.00	TEMECULA C A VAIL DAM	33-29-42	116-58-30	RIV	5000	SD	1948			G	829.		F
N*	1	X2-1701	11-0425.20	TEMECULA C A NIGGER CYN NR TEMECU	33-29-42	116-58-42	RIV	5000	SD	1923	1948		G	826.		F
O*	1	X2-1702	11-0426.00	TEMECULA C BL VAIL DM	33-29-42	116-58-42	RIV	5000	SD	1959			G			S
P	1	X2-1750	11-0424.10	TEMECULA C NR RADEC	33-27-48	116-55-42	RIV	5050	SD	1951	1954		F	345.		S
Q*	1	X2-1775	11-0424.00	TEMECULA C NR AGUANGA	33-27-30	116-55-24	RIV	5000	SD	1957			G	339.		F
R	1	X2-1800	11-0423.80	TEMECULA C BL AGUANGA VLY	33-26-42	116-53-48	RIV	5050	SD	1954	1954		F			S
S	1	X2-1815	11-0423.50	TEMECULA C AB AGUANGA	33-26-12	116-50-54	RIV	5050	SD	1953	1953		E			S
T	1	X2-1820	11-0423.00	TEMECULA C NR OAK VLY	33-24-18	116-49-00	SDG	5050	SD	1951	1954		F	158.		S
U*	1	X2-1935	11-0455.00	ONIELL D NR YSIDORA	33-19-42	117-19-42	SDG	5003	SD	1930			G			F
V	1	X2-2100	11-0424.80	LANCASTER C NR RADEC	33-28-06	116-52-48	RIV	5050	SD	1950	1951		G	298.		S
W	1	X2-2500	11-0424.60	COAHUILA C NR ANZA	33-31-30	116-48-18	RIV	5050	SD	1950	1954		F	207.		S
X*	3X	X2-2600	11-0424.30	COAHUILA C TRIB A ANZA	33-33-18	116-41-12	RIV	5103	SD	1961			G	12.7		L

* Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

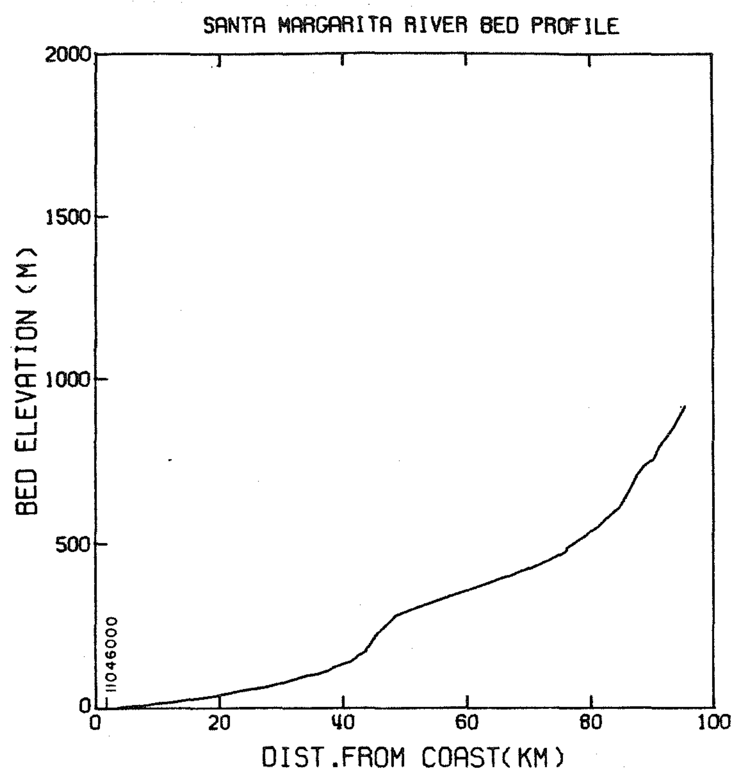

Figure C6-3 Bed profile of main channel of the Santa Margarita River.

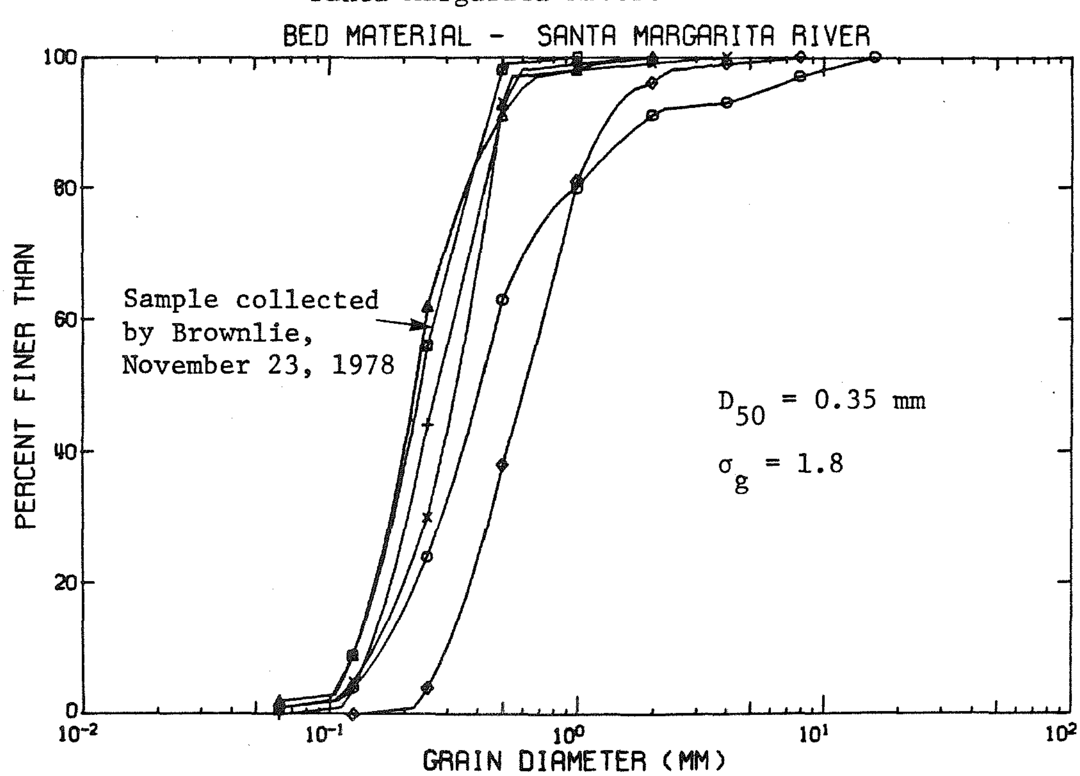

Figure C6-4 Composite bed-material samples collected at station 11046000 by the USGS between November 27, 1967, and August 16, 1973 and by Brownlie on November 23, 1978.

The proximity of the sediment gage to the coast would ordinarily be desirable for the determination of sediment delivery to the coastal system, however, the location of the gage on the upstream end of a tidal lagoon (Fig. C6-5) at the mouth of the river creates difficulties in sample collection.* During periods of low flow, a beach berm forms at the mouth and encloses the lagoon. When flows enter the lagoon, the water level rises, causing sediment to settle out of the flow, upstream of the gage. Following periods of high flow, as in 1969, the berm is broken, and the station is subject to tidal currents that superimpose on streamflow and create other problems.

In addition, it can be seen from Fig. C6-5 that the station is located on the outer downstream bank of a sharp bend in the channel. The secondary currents and turbulence caused by the bend create great sampling difficulties. To avoid these problems during 1978 water year the sediment samples were taken downstream at the Stuart Mesa Road bridge (Fig. C6-5). Consideration is now being given to moving the station downstream to this location.*

C6.6 Sediment Rating Curve

It was decided to adopt a rating curve that would represent sediment delivery into the coastal lagoon. The curve shown in Fig. C6-6 is based on 25 samples collected 1) during the 1969 water year (the year the berm was broken), and 2) all published and unpublished samples from 1970 to 1976 with discharges greater than 1 m^3/s. It is therefore hoped that the resulting curve avoids some of the problems associated with low flows, and represents sediment discharge into the lagoon rather than past the gaging station. Since the USGS publishes sediment discharge past the station, the resulting sediment yield for years with low flows should be considerably less

*Chris McConaughy, USGS, personal communication, September 1978.

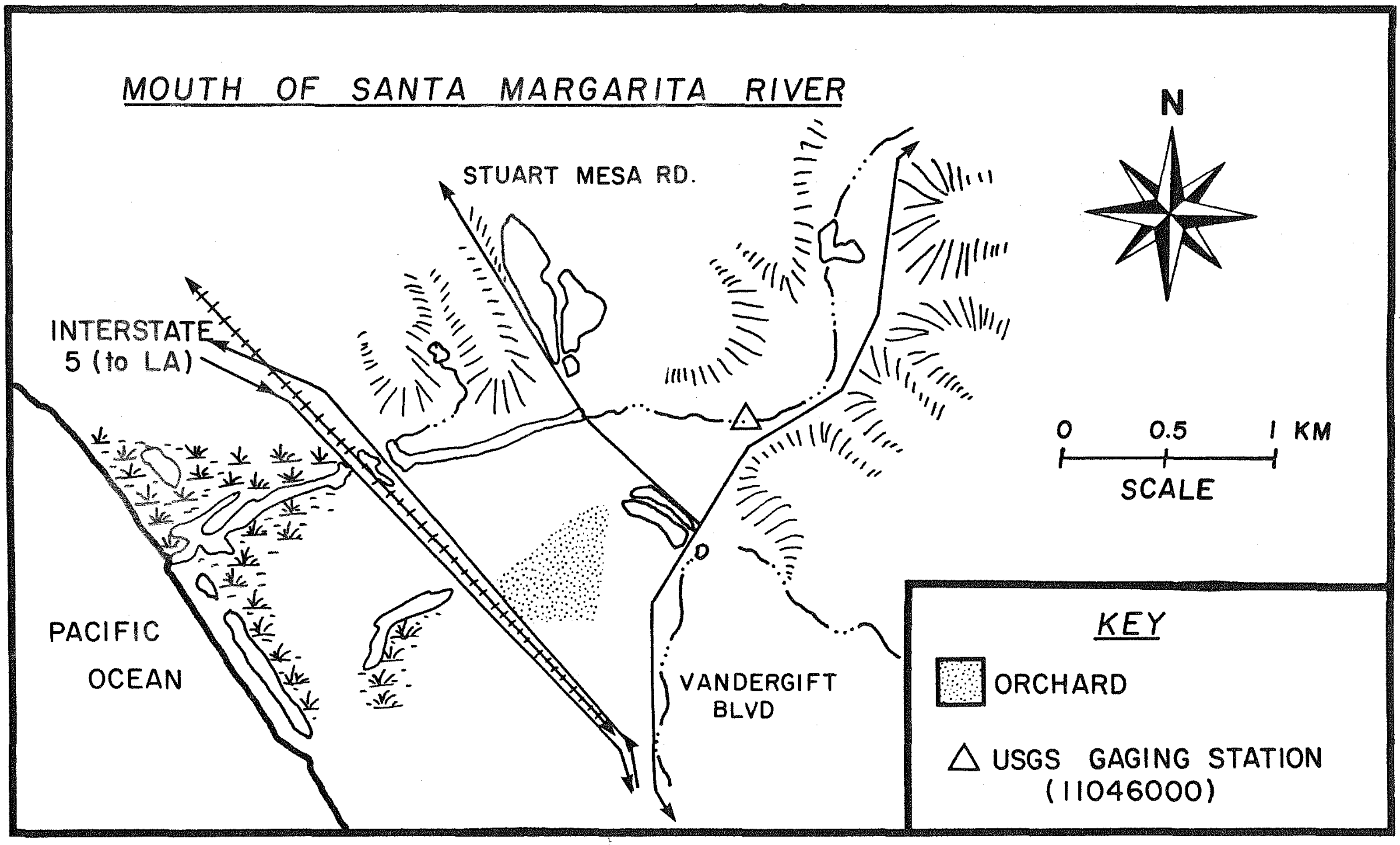

Figure C6-5 Lower reach of the Santa Margarita River.

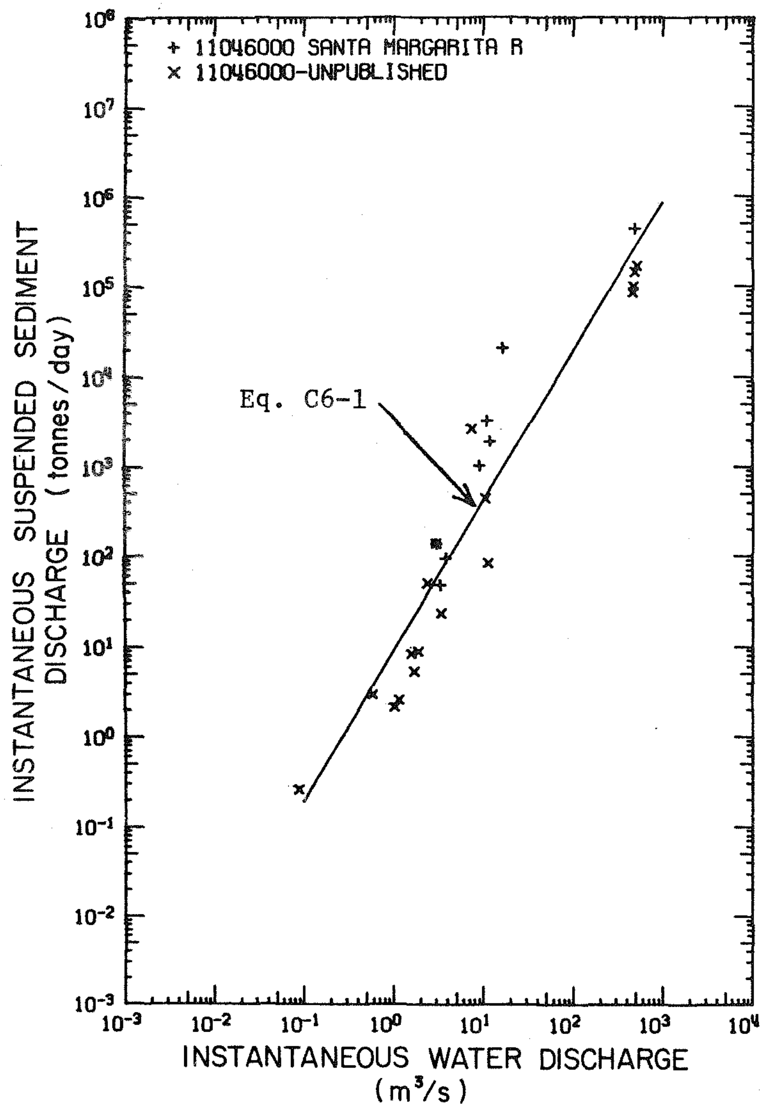

Figure C6-6 Relation of instantaneous sediment discharge to water discharge at Santa Margarita River station 11046000, 1969-76.

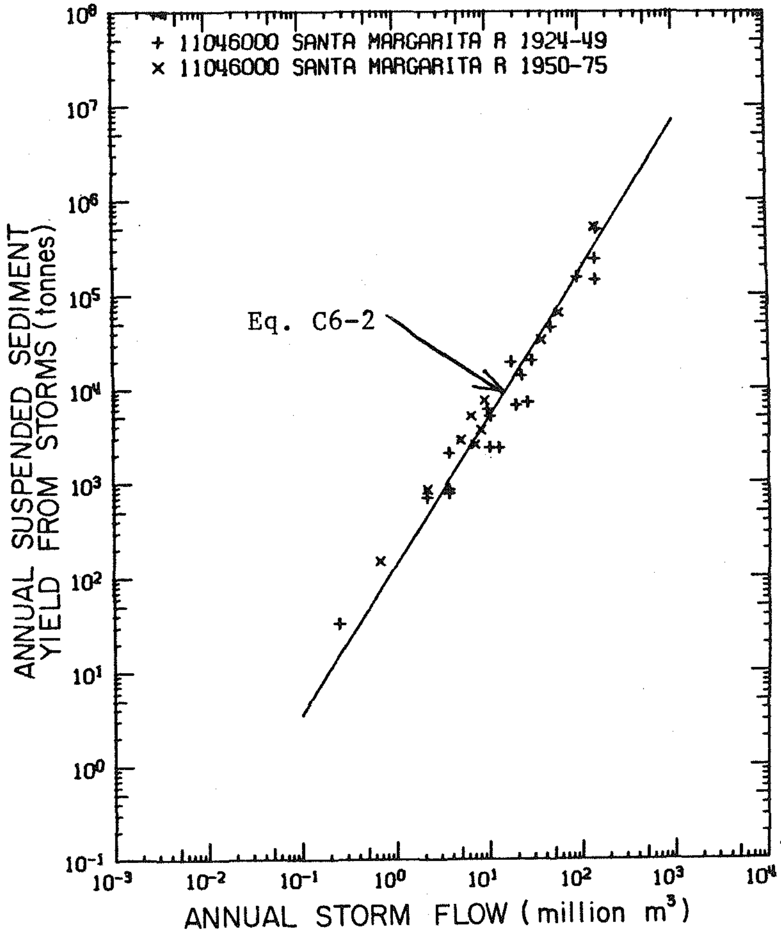

Figure C6-7 Relation of annual suspended sediment delivered by storms to annual storm flow at Santa Margarita River station 11046000, 1924-75.

than the results obtained from the curve in Fig. C6-6, which was fitted by the technique described in Section 18.1. The equation for the rating curve is

$$\hat{Q}_{ss} = 8.90\ Q^{1.66} \tag{C6-1}$$

where $\hat{Q}_{ss}$ is the predicted transport rate in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of Q_{ss} and Q is 0.951.

To determine the sediment yield that would have occurred under natural uncontrolled conditions, a relationship (Fig. C6-7) between annual suspended sediment yield produced by storms and annual storm flow was needed. From inspection of discharge records, it was decided that mean daily flows less than 1 m^3/s would be considered to be base flows, and the remaining flows would be considered to be storm flows. (A typical annual streamflow sequence is shown in Fig. C6-8.) The relationship, or annual sediment rating curve, is

$$\hat{\forall}_{ss}(\text{storm}) = 132[\forall(\text{storm})]^{1.58} \tag{C6-2}$$

where $\hat{\forall}_{ss}$(storm) is the predicted annual suspended sediment yield produced by storms, in tonnes, and $\forall$(storm) is the annual storm runoff, in million m^3. Equation C6-2, illustrated in Fig. C6-7, was determined by the method described in Section C18.2.

C6.7 Estimation of Natural Flows

Natural annual flows at the Ysidora station (11046000) were calculated as follows:

$$\forall_Y(\text{nat}) = \forall_Y(\text{act}) + \forall_{OD} + [\forall_V - P] \tag{C6-3}$$

where $\forall_Y$(act) is the actual annual flow at Ysidora, $\forall_{OD}$ is the flow

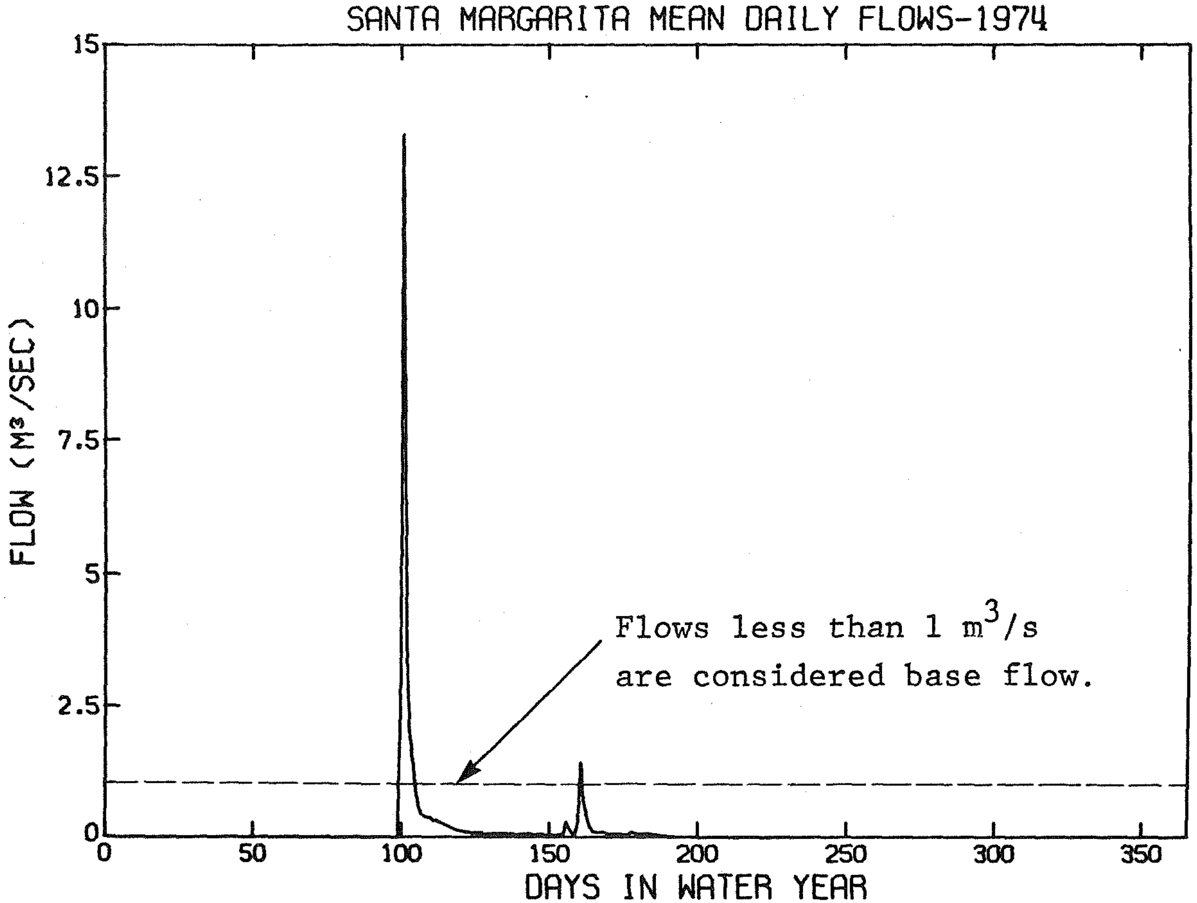

Figure C6-8 Typical annual sequence of mean daily flows (1974 water year) showing chosen cutoff between base flow and storm flows.

diverted by O'Neill Ditch, and $[\yen_V - P]$ is the natural flow from the area above Vail Dam, $\yen_V$, corrected for percolation losses, P, between the dam and Ysidora. $\yen_V$ is the total annual runoff reaching Vail Dam, is recorded at the gaging station (11042500) at the dam.

To estimate P, it was assumed that the rate of percolation between two stations in the central part of the reach is representative of the percolation along the entire reach. A nonlinear regression (see Section C18.3) was performed on the annual flows at the two stations, 11044500, near Fallbrook and 11044000, near Temecula (E and F, respectively, on Fig. C6-2). To account for local inflow, the upstream station (11044000) flows were scaled by 1.21, which is the ratio of the uncontrolled drainage areas (i.e., not including the area above Vail Lake) of the two stations. The resulting correlation (Fig. C6-9) is given by

$$\hat{\yen}_F = 1.5\ (1.21\ \yen_T)^{0.93} - 3.2 \qquad \text{(C6-4)}$$

where $\hat{\yen}_F$ is the predicted annual flow near Fallbrook and $\yen_T$ is the annual flow near Temecula. By scaling Eq. C6-4 by 4, which is the ratio of the distance between Vail Lake and Ysidora (56 km) and between Temecula and Fallbrook (14 km), an equation can be found that gives P directly:

$$P = 4(\yen_V - 1.5\yen_V^{0.93} + 3.2) \qquad \text{(C6-5)}$$

In the diversion record on the O'Neill Ditch, seven years of discharge data are missing (1961-67). For the first five of these years, there was no flow at Ysidora, thus we are assuming that there was no diversion during these years. For the last two years, in which there was actual flow at Ysidora, an unavoidable error was introduced in the calculation of natural flows. Therefore, for the water years 1966 and 1967, the estimates of natural suspended sediment yield will tend to be conservative.

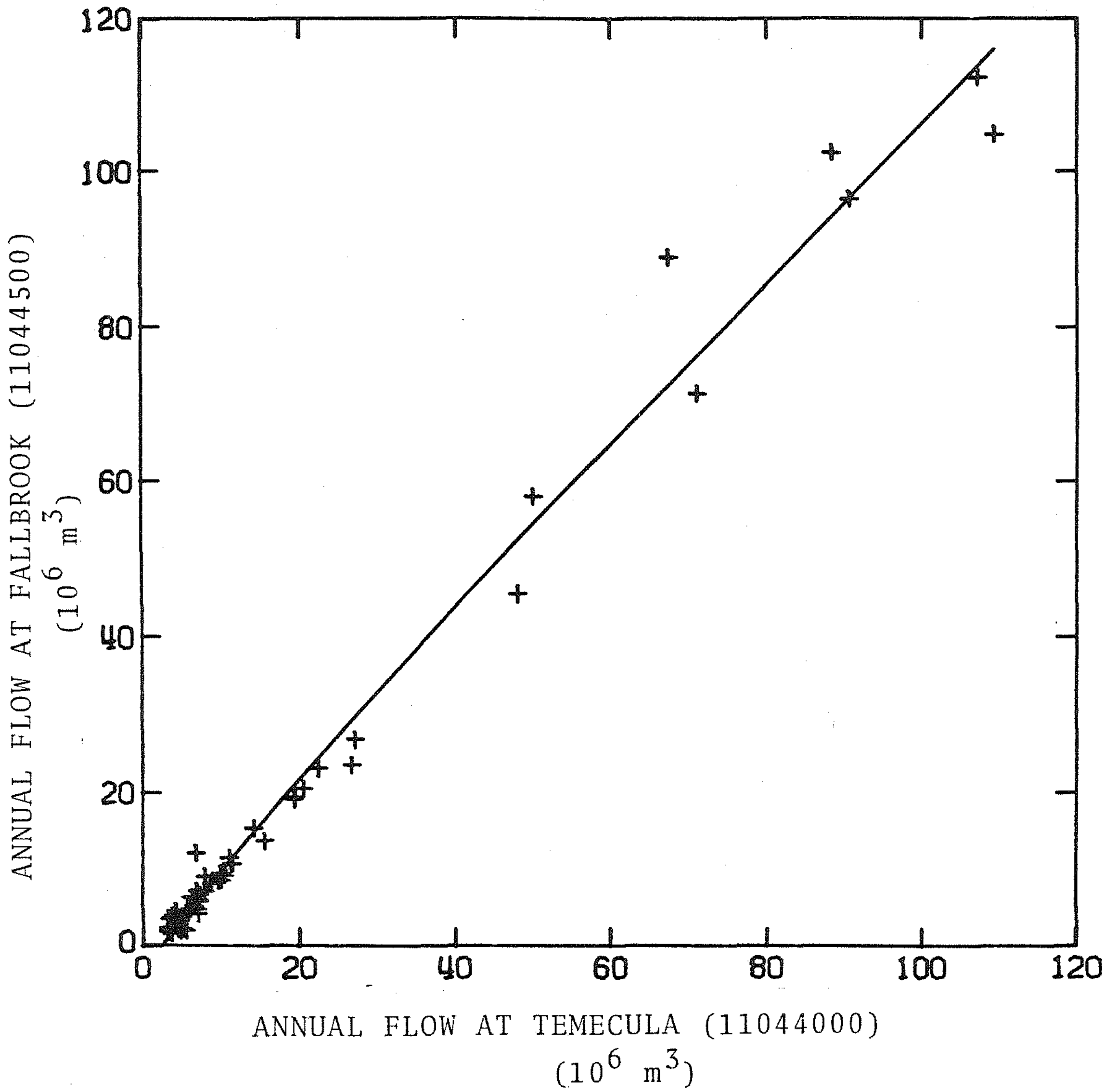

Figure C6-9 Correlation between annual flow at Fallbrook station 11044500 and Temecula station 11044000, used in predicting percolation rates.

By inspection of the discharge records, it was decided to assume that base flows and the suspended sediment delivered by base flows would have been about the same under natural conditions as under actual conditions. Therefore, natural storm flows could be determined by subtracting actual base flows from the total natural flows derived from Eq. C6-3.

C6.8 Annual Suspended Sediment Yield

The total annual suspended sediment yield is a combination of the suspended sediment produced by base flows and storm flows. For the period of record, both of these quantities were estimated for actual conditions using daily flow data and Eq. C6-1. Having determined natural annual storm flows, the corresponding natural suspended sediment yields were estimated from Eq. C6-2. The detailed results are given in Table C6-3, and the total cumulative suspended sediment yields are tabulated in Table C6-4 and plotted in Fig. C6-10.

C6.9 Summary

From the few particle size analyses of suspended sediment samples available for the Santa Margarita River, it is not possible to directly estimate the average annual suspended sand or bedload yield. However, from the experience of the northern rivers, it seems reasonable to take 25 percent as the average ratio of suspended sand yield to total suspended load yield and 10 percent as the average ratio of bedload yield to total suspended load yield, for both actual and natural conditions. Since the southern rivers drain a different geologic province than do the northern rivers, it is not clear that these assumptions are valid. Clearly, this is an area where more data is needed, particularly for high discharge events.

Table C6-3
Santa Margarita River (11046000)
Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)					ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)				
	1	2	3	1+2	1+3	4	5	6	4+5	4+6
WATER YEAR*	BASE FLOW	STORM ACT FLOW	STORM NAT FLOW	TOTAL ACT FLOW	TOTAL NAT FLOW	BASEFLOW SEDIMENT	STORM ACT SED	STORM NAT SED	TOTAL ACT SED	TOTAL NAT SED
1924 D	2.66	0.25	-1.00	2.91	-1.00	128.33	32.99	-1.00	161.32	-1.00
1925 D	0.97	0.0	-1.00	0.97	-1.00	30.31	0.0	-1.00	30.31	-1.00
1926 D	1.82	17.61	-1.00	19.43	-1.00	106.21	19307.27	-1.00	19413.48	-1.00
1927 A	-1.00	-1.00	-1.00	100.16	-1.00	-1.00	-1.00	-1.00	189869.88	-1.00
1928 A	-1.00	-1.00	-1.00	4.93	-1.00	-1.00	-1.00	-1.00	1641.46	-1.00
1929 A	-1.00	-1.00	-1.00	1.68	-1.00	-1.00	-1.00	-1.00	299.28	-1.00
1930 A	-1.00	-1.00	-1.00	7.19	-1.00	-1.00	-1.00	-1.00	2974.23	-1.00
1931 D	2.38	2.13	5.27	4.50	7.65	110.98	693.64	2909.22	804.62	3020.20
1932 D	3.42	46.64	50.41	50.07	53.84	189.40	45649.38	51607.66	45838.78	51797.06
1933 D	4.39	3.66	6.37	8.05	10.76	227.29	778.41	1866.25	1005.70	2093.54
1934 D	2.43	3.75	6.82	6.18	9.25	90.93	2061.00	5294.02	2151.93	5384.95
1935 D	5.67	10.36	11.78	16.03	17.45	351.10	2356.65	2888.33	2707.75	3239.43
1936 D	4.06	9.57	12.46	13.64	16.53	187.30	6054.14	9182.50	6241.45	9369.80
1937 D	2.56	142.00	145.05	144.56	147.61	151.75	236464.00	244525.25	236615.75	244677.00
1938 D	4.05	146.44	150.56	150.49	154.61	280.25	491480.63	513459.94	491760.88	513740.19
1939 D	2.65	25.60	28.06	28.25	30.71	182.84	7090.96	8197.23	7273.80	8380.07
1940 D	5.30	22.22	23.55	27.52	28.86	352.21	13801.51	15132.52	14153.71	15484.72
1941 D	3.33	141.71	143.95	145.03	147.28	269.38	143415.94	147017.38	143685.31	147286.75
1942 D	8.15	12.74	14.63	20.89	22.78	662.54	2316.52	2880.27	2979.06	3542.81
1943 D	2.75	88.87	90.29	91.62	93.04	159.63	153791.06	157692.06	153950.69	157851.69
1944 D	5.67	28.61	34.71	34.28	40.38	439.39	20025.75	27170.65	20465.14	27610.05
1945 D	5.94	19.07	21.88	25.01	27.82	429.61	6573.32	8164.03	7002.93	8593.64
1946 D	4.33	10.07	13.80	14.40	18.13	277.96	5012.25	8239.03	5290.21	8516.99
1947 D	4.85	3.70	6.17	8.55	11.02	305.25	844.26	1893.31	1149.51	2198.55
1948 D	0.69	0.0	6.10	0.69	6.79	26.00	0.0	2292.32	26.00	2318.33
1949 D	0.59	0.0	5.35	0.59	5.94	34.04	0.0	1864.56	34.04	1898.60
1950 N	0.0	0.0	2.36	0.0	2.36	0.0	0.0	512.65	0.0	512.65
1951 N	0.0	0.0	1.81	0.0	1.81	0.0	0.0	337.27	0.0	337.27
1952 D	2.35	56.40	71.66	58.75	74.01	173.77	64750.55	94467.75	64924.32	94641.50
1953 D	0.60	0.67	0.68	1.28	1.28	40.85	150.95	152.37	191.80	193.22
1954 D	1.35	8.20	13.56	9.54	14.91	75.02	3659.11	8101.55	3734.13	8176.58
1955 N	0.0	0.0	2.59	0.0	2.59	0.0	0.0	593.68	0.0	593.68
1956 N	0.0	0.0	0.48	0.0	0.48	0.0	0.0	41.53	0.0	41.53
1957 N	0.0	0.0	0.78	0.0	0.78	0.0	0.0	89.35	0.0	89.35
1958 D	0.40	37.06	52.15	37.46	52.55	15.04	33626.97	57636.84	33642.02	57651.89
1959 N	0.0	0.0	1.25	0.0	1.25	0.0	0.0	188.06	0.0	188.06
1960 N	0.0	0.0	0.84	0.0	0.84	0.0	0.0	100.43	0.0	100.43
1961 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966 D	2.00	6.42	7.06	8.42	9.06	113.08	5119.19	5947.76	5232.27	6060.84
1967 D	3.90	8.93	22.81	12.83	26.71	241.23	7548.23	33150.41	7789.46	33391.64
1968 N	0.0	0.0	1.62	0.0	1.62	0.0	0.0	283.12	0.0	283.12
1969 D	1.67	142.36	175.02	144.03	176.69	109.56	518852.81	718793.81	518962.38	718903.38
1970 D	0.75	4.99	5.86	5.73	6.61	38.24	2871.38	3708.92	2909.62	3747.16
1971 N	0.0	0.0	1.76	0.0	1.76	0.0	0.0	322.69	0.0	322.69
1972 N	0.0	0.0	1.08	0.0	1.08	0.0	0.0	149.32	0.0	149.32
1973 D	1.44	7.11	11.93	8.55	13.37	85.45	2553.75	5784.55	2639.20	5870.00
1974 D	0.96	2.15	4.69	3.11	5.65	41.09	853.33	2923.07	894.42	2964.16
1975 N	0.0	0.0	2.82	0.0	2.82	0.0	0.0	678.98	0.0	678.98

NOTES: Negative one (-1.00) indicates data unavailable.

Table C6-4
Santa Margarita River (11046000)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1931 D	0.00	0.00
1932 D	0.05	0.05
1933 D	0.05	0.06
1934 D	0.05	0.06
1935 D	0.05	0.07
1936 D	0.06	0.07
1937 D	0.30	0.32
1938 D	0.79	0.83
1939 D	0.79	0.84
1940 D	0.81	0.86
1941 D	0.95	1.00
1942 D	0.96	1.01
1943 D	1.11	1.17
1944 D	1.13	1.19
1945 D	1.14	1.20
1946 D	1.14	1.21
1947 D	1.14	1.21
1948 D	1.14	1.22
1949 D	1.14	1.22
1950 N	1.14	1.22
1951 N	1.14	1.22
1952 D	1.21	1.31
1953 D	1.21	1.31
1954 D	1.21	1.32
1955 N	1.21	1.32
1956 N	1.21	1.32
1957 N	1.21	1.32
1958 D	1.25	1.38
1959 N	1.25	1.38
1960 N	1.25	1.38
1961 N	1.25	1.38
1962 N	1.25	1.38
1963 N	1.25	1.38
1964 N	1.25	1.38
1965 N	1.25	1.38
1966 D	1.25	1.39
1967 D	1.26	1.42
1968 N	1.26	1.42
1969 D	1.78	2.14
1970 D	1.78	2.14
1971 N	1.78	2.14
1972 N	1.78	2.14
1973 D	1.78	2.15
1974 D	1.78	2.15
1975 N	1.78	2.15

*Suspended sand plus washload.
**Actual based on: D-Daily Flows, U-USGS Estimates; N-No Flow.

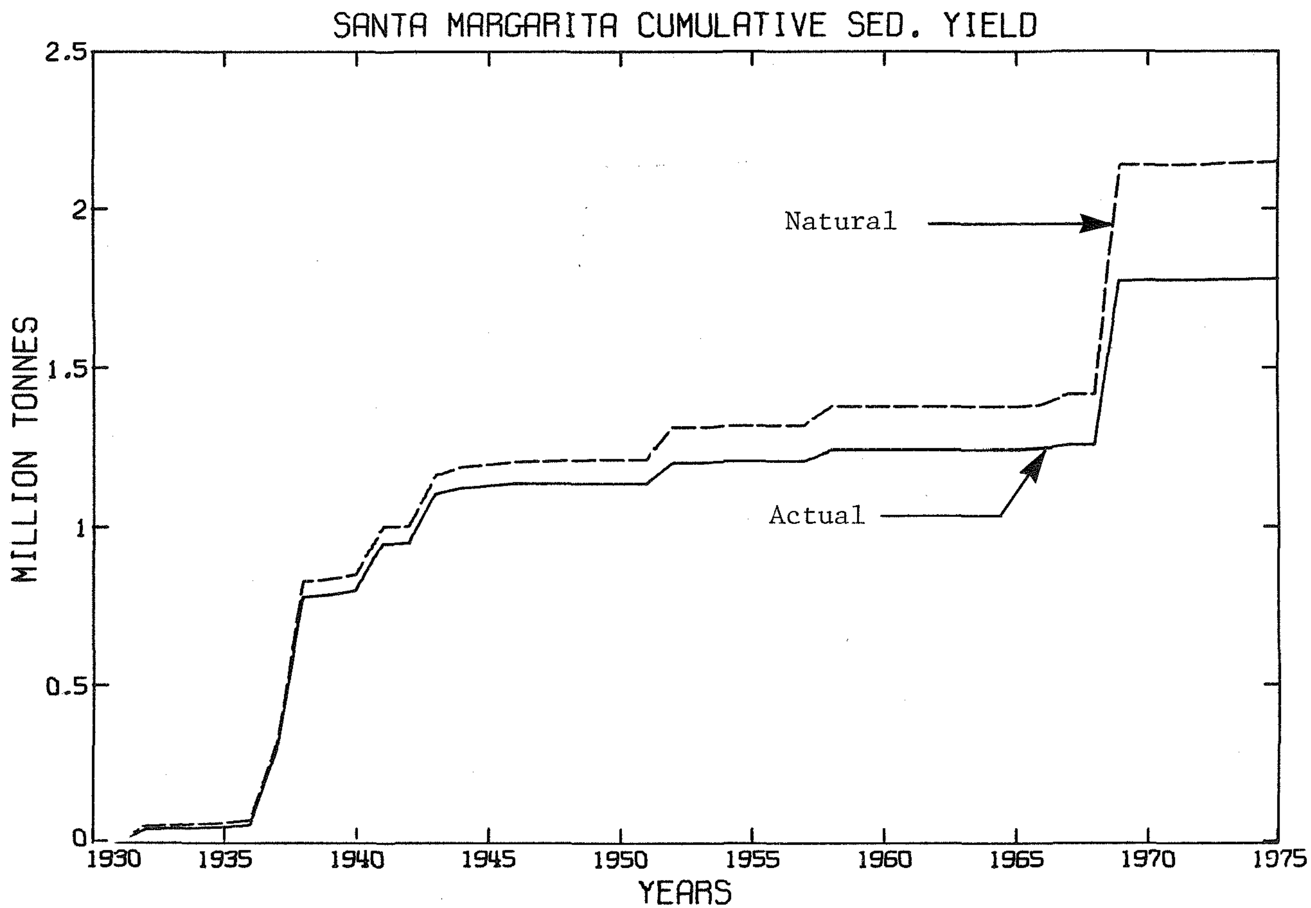

Figure C6-10 Cumulative natural and actual suspended sediment yield at Santa Margarita River station 11046000.

Using the percentages from the preceding paragraph, the average annual bedload and suspended sand yields for various time periods for actual and natural conditions have been approximated and are presented in Table C6-5. The table shows that even under natural conditions the Santa Margarita River would have been a low sediment producer. By way of contrast, the Ventura River with a drainage area of less than one third that of the Santa Margarita River would have had a natural total sediment yield of more than 17 times that of the Santa Margarita River for the period 1933 through 1975. The difference can be explained in part by the lower average rainfall over the Santa Margarita River basin and the higher percolation rates there.

Table C6-5

Santa Margarita River Average Annual Sediment Yield

Mode of Transport and Sediment Size Class	Annual Sediment Yield in Tonnes: Total Period of Record 1931 - 75		Period of Maximum Control 1950 - 75		Largest Event 1969 Water Year	
	Actual	Natural	Actual	Natural	Actual	Natural
Total Suspended Load	39,600	47,800	24,600	35,800	519,000	719,000
Suspended Fines (wash load)	29,700	35,800	18,500	26,800	389,000	539,000
Suspended Sand	9,890	11,900	6,150	8,940	130,000	180,000
Estimated Bedload (sand and gravel)	3,960	4,780	2,460	3,580	51,900	71,900
Total Sand and Gravel (bed-material load)	13,900	16,800	8,610	12,500	182,000	252,000
Total Sediment Load	43,500	52,500	27,100	39,300	571,000	791,000
$\frac{\text{Actual Sand Yield}}{\text{Natural Sand Yield}}$ (%)	83%		69%		72%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C7 San Luis Rey River Basin

C7.1 Drainage Basin Description

The San Luis Rey River basin is located in northern San Diego County. The basin is bounded on the north by the Santa Margarita River basin and on the southeast by the San Dieguito River basin. It covers an area of 1450 km^2, of which 30 percent is agriculturally developed and approximately 6 percent is urbanized.

The basin has varied topography, rainfall and vegetal cover. Palomar Mountain, with an elevation of 1870 m and an average rainfall (1941-1971) of 56 cm, has a coniferous forest near the summit and an oak woodland at lower elevations. The remainder of the basin (average rainfall 30-45 cm) is dominated by chaparral, with a small grassland east of Lake Henshaw and a coniferous forest at the eastern drainage divide. The western part of the basin is covered with a number of groves and avocado orchards.

C7.2 Geologic Setting

The San Luis Rey River drains portions of the Peninsular Ranges province in southern California, flowing across a terrain composed largely of crystalline rocks of the southern California batholith. These include igneous rocks of various granitic compositions and those that they intruded over 100 million years ago--Mesozoic and Paleozoic meta-sedimentary and meta-volcanic rocks. These older rocks are concealed to the west by younger marine sediments of Eocene and Miocene age. More recently, wave action cut several terraces in the older rocks along coastal reaches of the drainages as the area emerged during Pleistocene time.

Outside of general uplift, tectonic activity has been confined mainly to the Elsinore fault zone. This zone has downdropped the regions along it and east of it, producing topographic contrast with the terrain to the west.

C7.3 Control Facilities

Lake Henshaw, which was completed on October 7, 1922, is the only major storage facility on the San Luis Rey River basin. The capacity and drainage area of the reservoir, which is owned by the Vista Irrigation District, are given in Table C7-1. Water from Lake Henshaw is released down the main channel of the San Luis Rey River and diverted to Wohlford Lake in the Escondido Creek basin, via the Escondido Mutual Water Company's canal 15 km downstream.

The Escondido Mutual Water Company canal, which began operation in 1896, acts as a conduit for releases from Lake Henshaw and for diverted runoff from below Lake Henshaw. The water is used primarily for irrigation and for the Rincon Indian Reservation. Wohlford Lake acts as an intermediate storage facility.

In addition to the two major facilities, three small reservoirs, Guajome Lake, Windmill Lake, and Whelan Lake, are shown on Fig. C7-1. These reservoirs have been considered to have had only a minor effect on the sediment yield of the river, and have not been dealt with in this report.

C7.4 Gaging Stations

Gaging station locations in the basin are shown in Fig. C7-2 and are tabulated in Table C7-2. The stations have been tabulated according to their length of record, e.g., stations with 15 years of record or more, stations with less than 15 years of record. Of the 32 stations, only nine stations have records of more than 15 years. Of these nine stations, three are located upstream of Lake Henshaw, one is located on the diversion canal, and the remaining five are downstream of the dam. Seven of the 32 stations are maximum discharge, crest-stage stations.

C7.5 Stream Bed Characteristics

In Fig. C7-3 the bed elevation is plotted against distance from the coast for the main channel of the San Luis Rey River and two tributaries. The average slopes of the two tributaries, Key Canyon Creek and Moosa Canyon Creek, are 20.3 and 15.1 m/km respectively, in comparison to the gently sloping main channel into which they discharge, which has an average slope of 3.00 m/km for the lower 40 km. The steepest parts of the main channel are found in the uppermost reaches, and in the region 60 to 65 km inland, where the local slope is 55.5 m/km.

An on the Santa Margarita River, the sediment gaging station (11042000) on the San Luis Rey is near the coast, being only 1.8 km upstream from the mouth of the river (local slope = 1.31 m/km). Particle-size distributions of three composite surface bed-material samples collected at this station by the USGS between January 19, 1970, and August 16, 1973, and one collected by Brownlie on November 23, 1978, are shown in Fig. C7-4. Three of the samples have an average median diameter of 0.26 mm and an average geometric standard deviation of 1.7. The fourth sample, indicated by crosses (+) on Fig. C7-4, was not included because it is believed to represent an armored bed condition.

The gaging station (see Fig. C7-5) is located upstream from the point where Loretta Street crosses the channel, thereby creating great sampling difficulties. The crossing is formed by an earth embankment with three circular culverts having a total capacity of between 2 and 3 m^3/s. During low flows, sediment samples are collected at the upstream end of each culvert and the resulting concentrations are averaged.* During higher flows, the road is overtopped and sediment samples are collected from the flow over the road only. In either case water ponds behind the embankment, temporarily trapping sediment. During major storms, such as during 1969, the channel is washed clear of debris and the crossing is destroyed.

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*Chris McConaughy, USGS, personal communication, September 1978.

Table C7-1

Control Structures of the San Luis Rey River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
Lake Henshaw	240	October 1922	531

Diversion Facility	Completion Date	Diversion To/From
Escondido Mutual Water Company Canal	1896	A gravity canal diverts water from San Luis Rey River channel to Wohlford Lake and Rincon Indian Reservation in the Escondido Creek drainage basin.

NOTES:

Total area of the San Luis Rey basin is 1450 km^2.

At least four other minor diversions have operated at various times and there are three small storage reservoirs that have not been listed: Guajome Lake, Windmill Lake, and Whelan Lake.

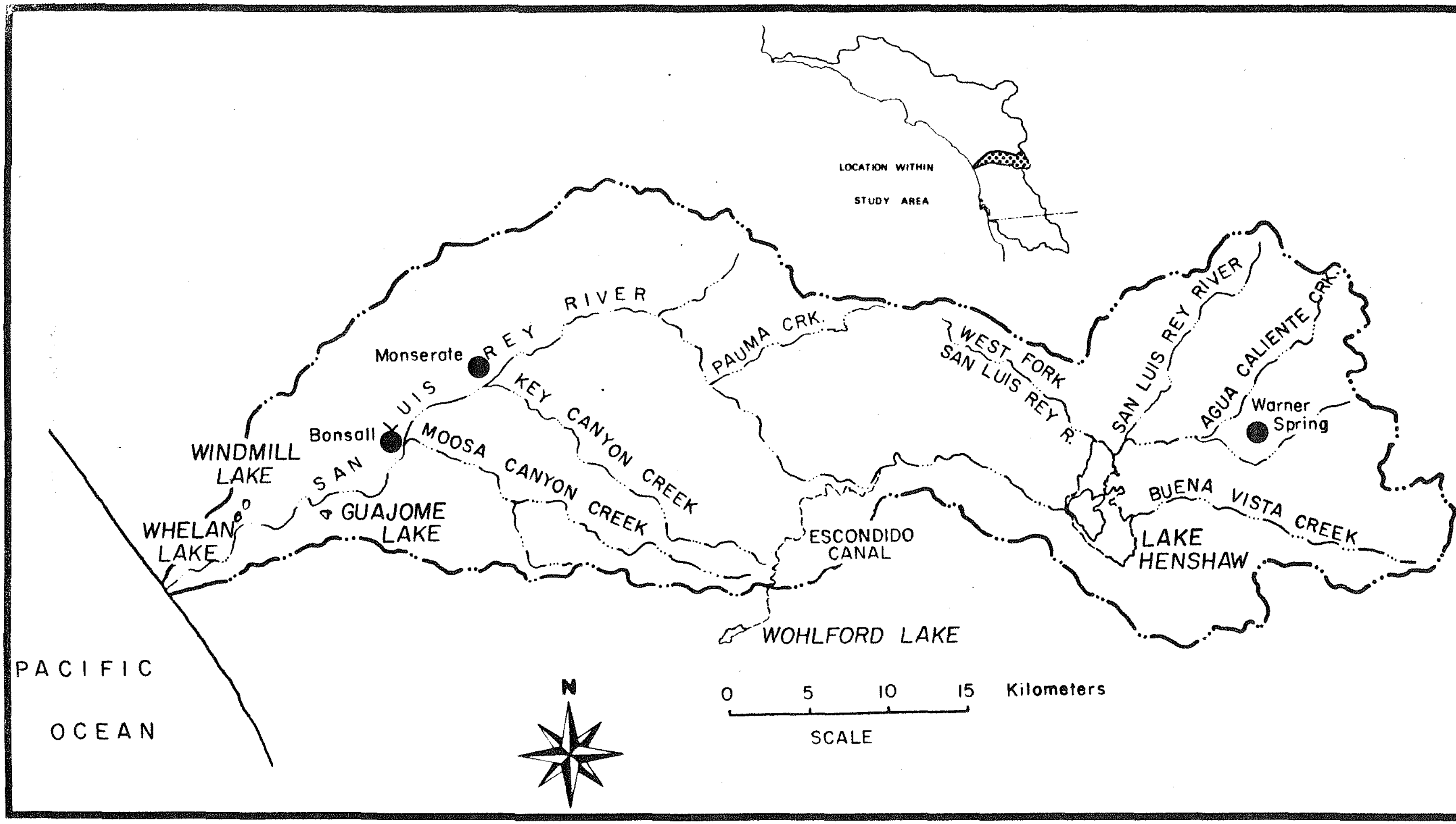

Figure C7-1 San Luis Rey River basin.

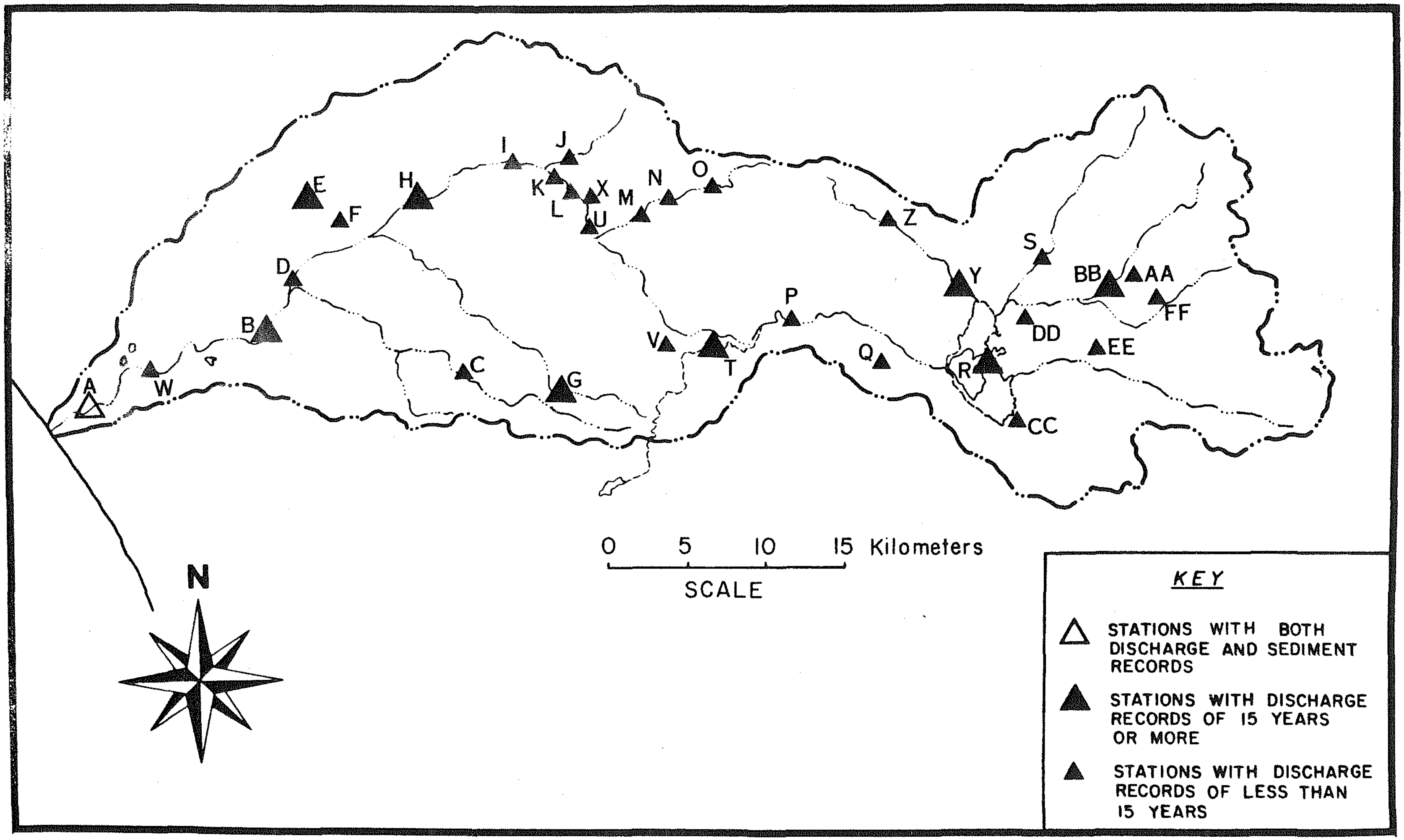

Figure C7-2 Location of streamflow and sediment gaging stations within the San Luis Rey River basin.

Table C7-2
Gaging Stations within the San Luis Rey River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°-MIN'-SEC"	LONGITUDE DEG°-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A*	1	X3-1100	11-0420.00	SAN LUIS REY R A OCEANSIDE	33-12-48	117-22-30	SDG	5000	SD	1912		21	G	1443.		F
B*	1	X3-1175	11-0410.00	SAN LUIS REY R NR BONSALL	33-15-13	117-14-48	SDG	5000	SD	1916		11	G	1329.		F
C	3X	X3-1210		MOOSA CYN A ARTESIAN LK	33-15-30	117-09-18	SDG	1401	SD	1970			E	76.7		L
D	6	X3-1230	11-0405.00	SAN LUIS REY R A BONSALL	33-17-12	117-13-18	SDG	5000	SD	1912	1916		G	1179.		F
E*	3X	X3-1245		SAN LUIS REY R TRIB IN LIVE OAK P	33-21-36	117-12-12	SDG	1401	SD	1960		5	G	9.07		L
F	3X	X3-1250	11-0404.00	SAN LUIS REY R TRIB NO2 NR FALLBR	33-21-36	117-12-12	SDG	5000	SD	1961	1973		G	0.93		F
G*	3X	X3-1270	11-0402.00	KEYS C TRIB A VALLEY CENTER	33-13-45	117-02-09	SDG	5000	SD	1963		1	F	19.7		F
H*	1	X3-1300	11-0400.00	SAN LUIS REY R A MONSERATE NARROW	33-20-12	117-08-12	SDG	5000	SD	1935		5	G	966.		F
I	6	X3-1345	11-0395.00	SAN LUIS REY R A PALA	33-21-42	117-04-24	SDG	5000	SD	1912	1912		P	860.		F
J	3X	X3-1380	11-0391.00	SAN LUIS REY R TRIB NR PALA	33-21-45	117-02-55	SDG	5000	SD	1961	1973		G	2.62	158	F
K	2	X3-1400	11-0390.00	SAN LUIS REY R BL PAL DIVDM NR PA	33-21-24	117-02-24	SDG	5000	SD	1944	1957		G	837.		F
L	1	X3-1470	11-0385.00	SAN LUIS REY R NR PALA	33-20-12	117-01-48	SDG	5000	SD	1903	1916		G	821.		F
M	1	X3-1510	11-0377.00	PAUMA C NR PAUMA VLY	33-20-12	116-58-24	SDG	5000	SD	1964			G	285.		F
N	1	X3-1515	11-0375.00	PAUMA C A PAUMA IND RESERVATION	33-20-18	116-58-06	SDG	5000	SD	1921	1921		G	28.0		F
C	1	X3-1555	11-0370.00	PAUMA C NR NELLIE	33-20-54	116-54-42	SDG	5000	SD	1920	1921		G	12.7		F
P	1	X3-1675	11-0355.00	SAN LUIS REY R NR NELLIE	33-16-06	116-53-18	SDG	5000	SD	1915	1924		G	616.		F
Q	3X	X3-1700	11-0353.00	WIGHAM C NR HENSHAW LK	33-15-30	116-47-54	SDG	5000	SD	1965	1973		E			SF
R*	9	X3-1740	11-0350.00	SAN LUIS REY R A LK HEN SHAW	33-14-18	116-45-42	SDG	4405	SD	1922	1968		G	534.		F
S	1	X3-1800	11-0310.00	SAN LUIS REY R NR WARNER SPRINGS	33-18-24	116-41-36	SDG	5000	SD	1913	1916		G	87.0		F
T*	6	X3-1920	11-0360.00	ESCONDIDO MU WTR CO CA NR NELLIE	33-16-00	116-53-30	SDG	5711	SD	1896			G			F
U	1	X3-1925	11-0376.50	PAUMA VALLEY WATER CO. DIV. NR PA	33-20-18	116-58-12	SDG	5000	SD	1964			E			SF
V	6	X3-1940	11-0365.00	RINCON IND RESER D NR VAL CENTER	33-15-48	116-57-06	SDG	5000	SD	1912	1912		G			F
W	9	X3-1960	11-0415.00	SAN LUIS REY D NR SAN LUIS REY	33-15-00	117-17-36	SDG	5000	SD	1913	1913		F			L
X	6	X3-1980	11-0380.00	PALA IND RESER CA A PALA	33-21-30	117-04-24	SDG	5000	SD	1912	1914		G			F
Y*	1	X3-2100	11-0330.00	SAN LUIS REY R.WF.NR WARNER SPR	33-17-48	116-45-30	SDG	5000	SD	1913			G	66.1		F
Z	1	X3-2200	11-0325.00	SAN LUIS REY R.WF.NR NELLIE	33-18-36	117-48-18	SDG	5000	SD	1920	1921		G	36.5		F
A1	3X	X3-3070	11-0321.00	AQUA CALIENTE C TRIB NR WARNER SP	33-16-06	116-39-18	SDG	5000	SD	1961	1973		G	0.13		F
B1*	1X	X3-3100	11-0315.00	AGUA CALIENTE C NR WARNER SPRINGS	33-17-18	116-39-12	SDG	5000	SD	1961			P	49.2		F
C1	9	X3-4100	11-0345.00	MATAGUAL C NR WARNER SPRINGS	33-13-12	116-40-42	SDG	5000	SD	1914	1915		G	19.9		F
D1	6	X3-5100	11-0340.00	SUSANNA C NR WARNER SPRINGS	33-12-00	116-42-30	SDG	5000	SD	1913	1916		G	11.8		F
E1	6	X3-6100	11-0335.00	CARRISTA C NR WARNER SPRINGS	33-11-48	116-42-00	SDG	5000	SD	1913	1916		G	12.7		F
F1	1	X3-7100	11-0320.00	CANADA VERDE C NR WARNER SPR	33-16-24	116-36-48	SDG	5050	SD	1913	1915		P	6.01		L

*Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

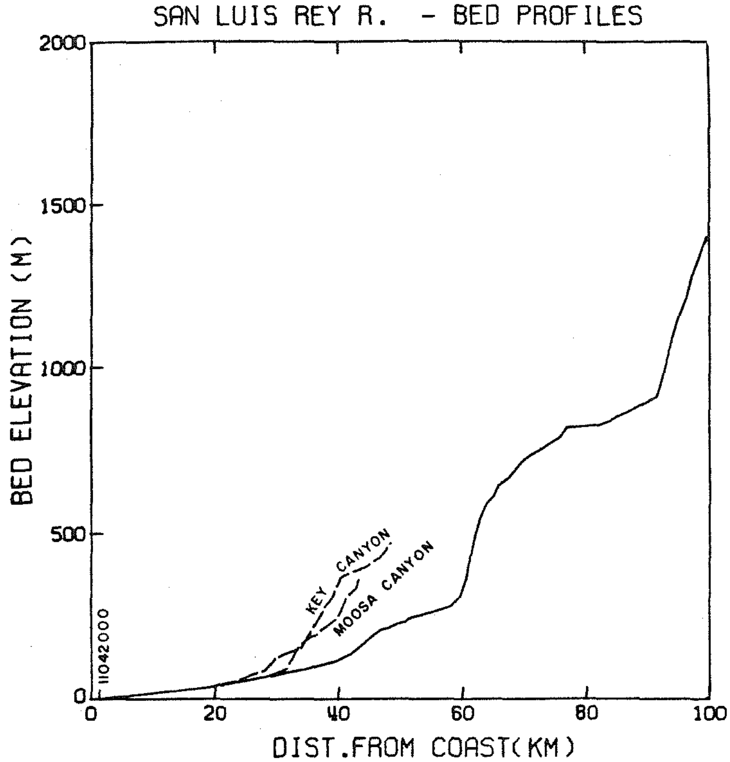

Figure C7-3 Bed profile of main channel of San Luis Rey River (solid line and two tributaries (dashed lines).

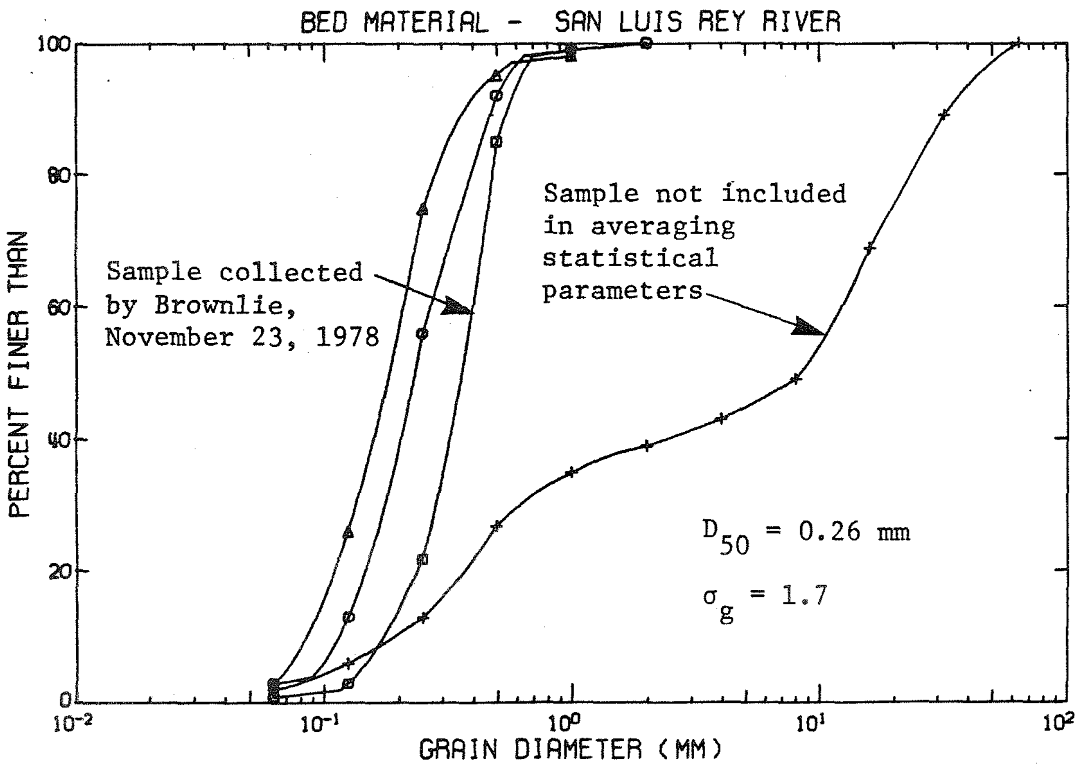

Figure C7-4 Composite bed-material samples collected at station 11042000 by the USGS between January 19, 1970 and August 16, 1973 anf by Brownlie on November 23, 1978 the road only. In either case water ponds behind the embankment, temporarily trapping sediment. During major storms, such as during 1969, the channel is washed clear of debris and the crossing is destroyed.

C7.6 Sediment Rating Curve

Actual suspended sediment yields for the water years in which daily streamflow data were available were estimated with the use of an instantaneous sediment rating curve. To avoid the problems created by the Loretta Street Crossing, only samples collected during the 1969 water year have been used in developing a rating curve. The curve shown in Fig. C7-6 best represents the sediment discharge into the trap created by the crossing. The accumulated material should eventually be delivered to the coast during major storms. As the USGS publishes sediment discharge passing the station, their results will not necessarily be in agreement with results derived from the curve in Fig. C7-6. The instantaneous rating curve was fitted by the technique described in Section 18.1. The equation for the rating curve is

$$\hat{Q}_{ss} = 26.0\ Q^{1.78} \qquad \text{(C7-1)}$$

where $\hat{Q}_{ss}$ is the predicted transport rate in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of Q_{ss} and Q is 0.985.

To determine the sediment yield that would have occurred under natural conditions for the total period of record, and actual conditions for the period when no daily flow data were available (1942 through 1946), an annual rating curve (Fig. C7-7) was developed. To improve the relationship, base flows were removed and only annual storm flow quantities were correlated. From inspection of streamflow records, it was decided that mean daily flows less than 1 m^3/s would

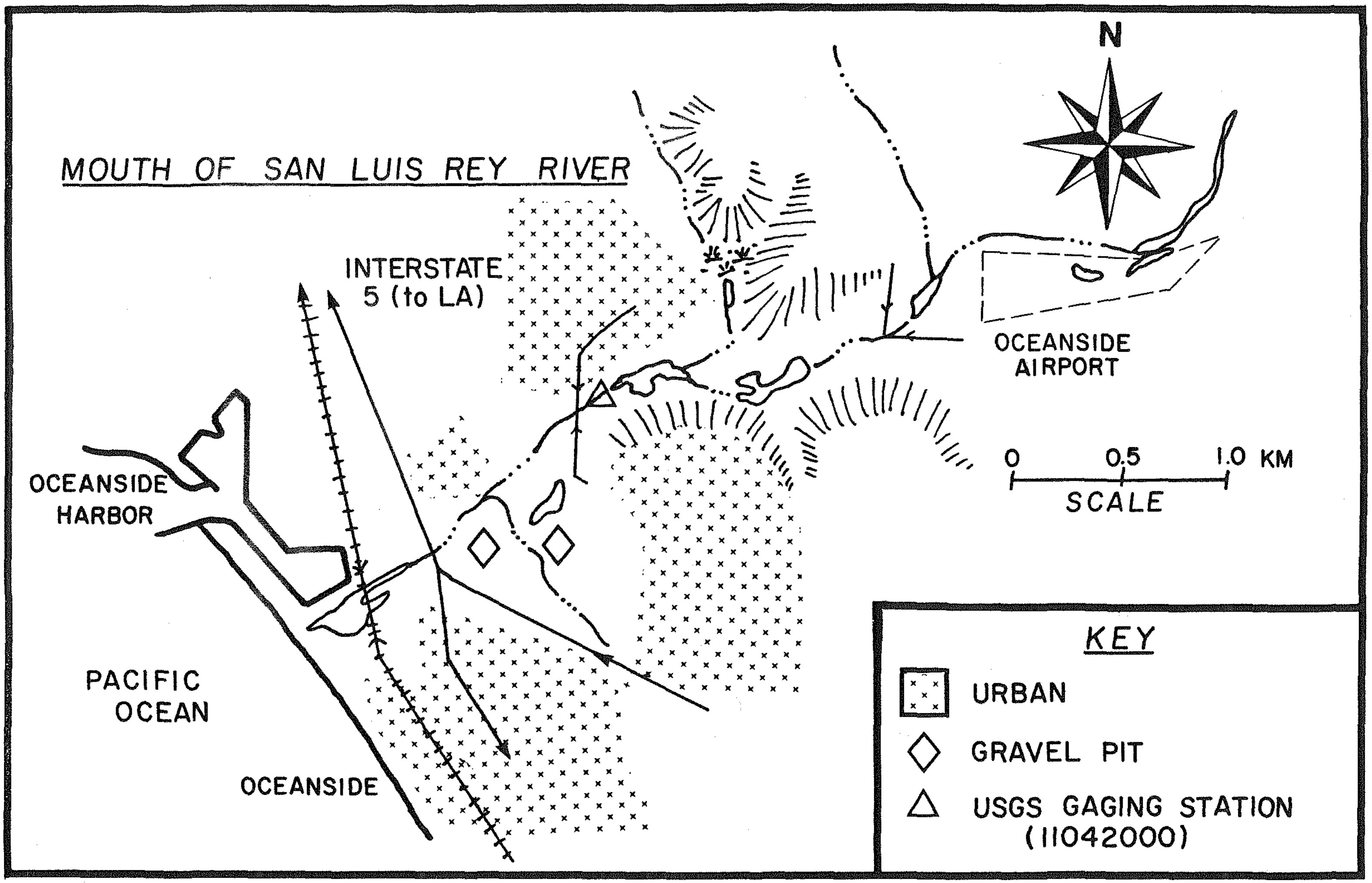

Figure C7-5 Lower reach of the San Luis Rey River.

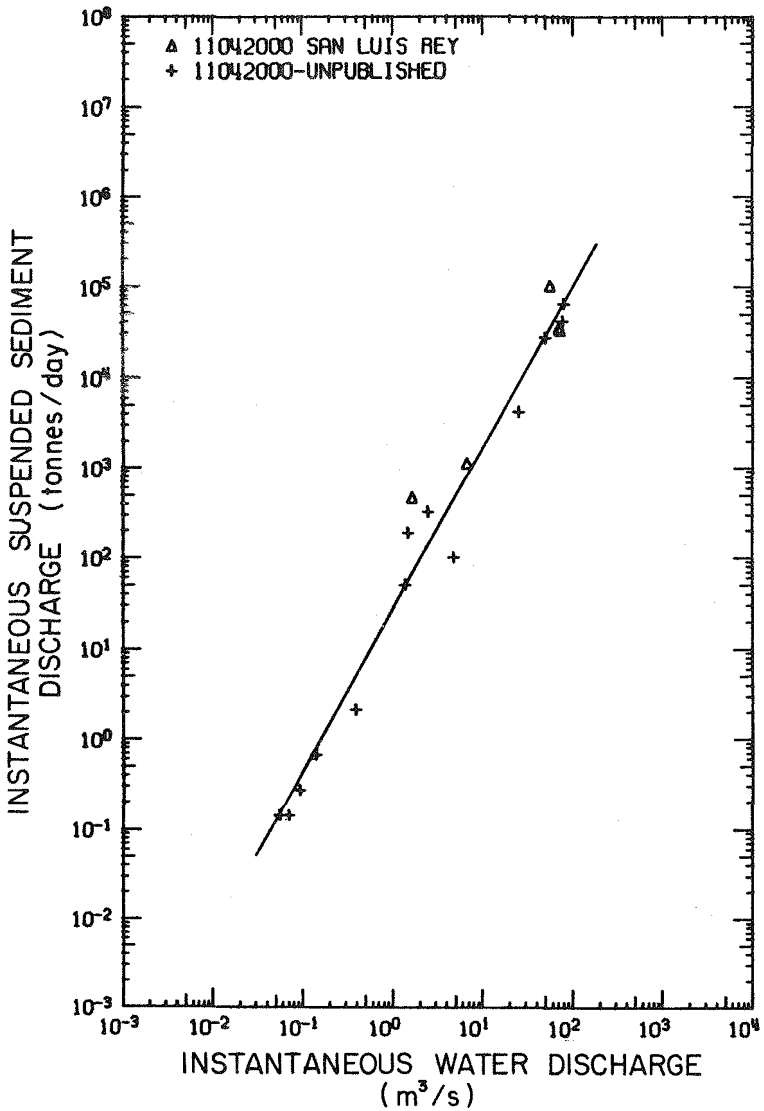

Figure C7-6 Relation of instantaneous sediment discharge to water discharge at San Luis Rey River station 11042000, 1969 water year.

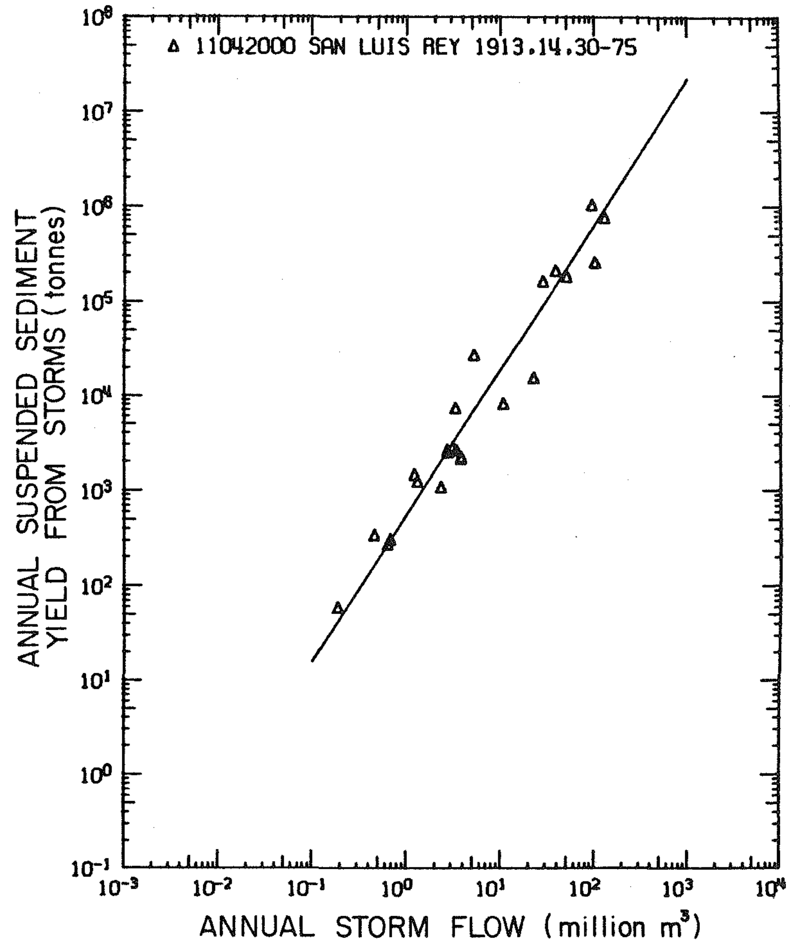

Figure C7-7 Relation of annual suspended sediment delivered by storms to annual storm flow at San Luis Rey River station 11042000, 1913, -14, 30-75.

be considered to be base flows, and the remaining flows would be considered to be storm flows. (A typical annual streamflow sequence is shown in Fig. C7-8.) The relationship, or the annual sediment rating curve, is

$$\hat{\forall}_{ss}(\text{storm}) = 544[\forall(\text{storm})]^{1.54} \qquad \text{(C7-2)}$$

where $\hat{\forall}_{ss}$(storm) is the predicted annual suspended sediment yield produced by storms, in tonnes, and $\forall$(storm) is the annual storm runoff, in million m^3. Equation C7-2, illustrated in Fig. C7-7, was determined by the method described in Section 18.2.

C7.7 Estimation of Natural Flows

Natural annual flows at the Oceanside station were calculated by adding predicted natural annual flows at the Escondido Mutual Water Company canal, which are corrected for percolation, to actual annual flow at Oceanside. The calculations are summarized below:

$$\forall_O(\text{nat}) = \forall_O(\text{act}) + 0.8\ [\forall_E(\text{nat}) - \forall_w] \qquad \text{(C7-3)}$$

where $\forall_O$(nat) and $\forall_O$(act) are the natural and actual annual flows at Oceanside, 0.8 is a percolation correction, $\forall_E$(nat) is the natural annual flow at the Escondido Canal, and $\forall_w$ is the annual waste at the canal (i.e., water that is not diverted from the stream channel).

The values for $\forall_E$(nat) and $\forall_w$ were supplied by the Escondido Mutual Water Company. $\forall_O$(act) values were obtained from USGS records, with the exception of the period from 1942 to 1946, for which no discharge records were kept at Oceanside. A regression analysis (Section C18.3) was run between annual flows at Oceanside, $\forall_O$(act), and annual flows at Bonsall, $\forall_B$(act), giving the relationship.

$$\hat{\forall}_O(\text{act}) = 0.830[\forall_B(\text{act})]^{1.03} - 1.32 \qquad \text{(C7-4)}$$

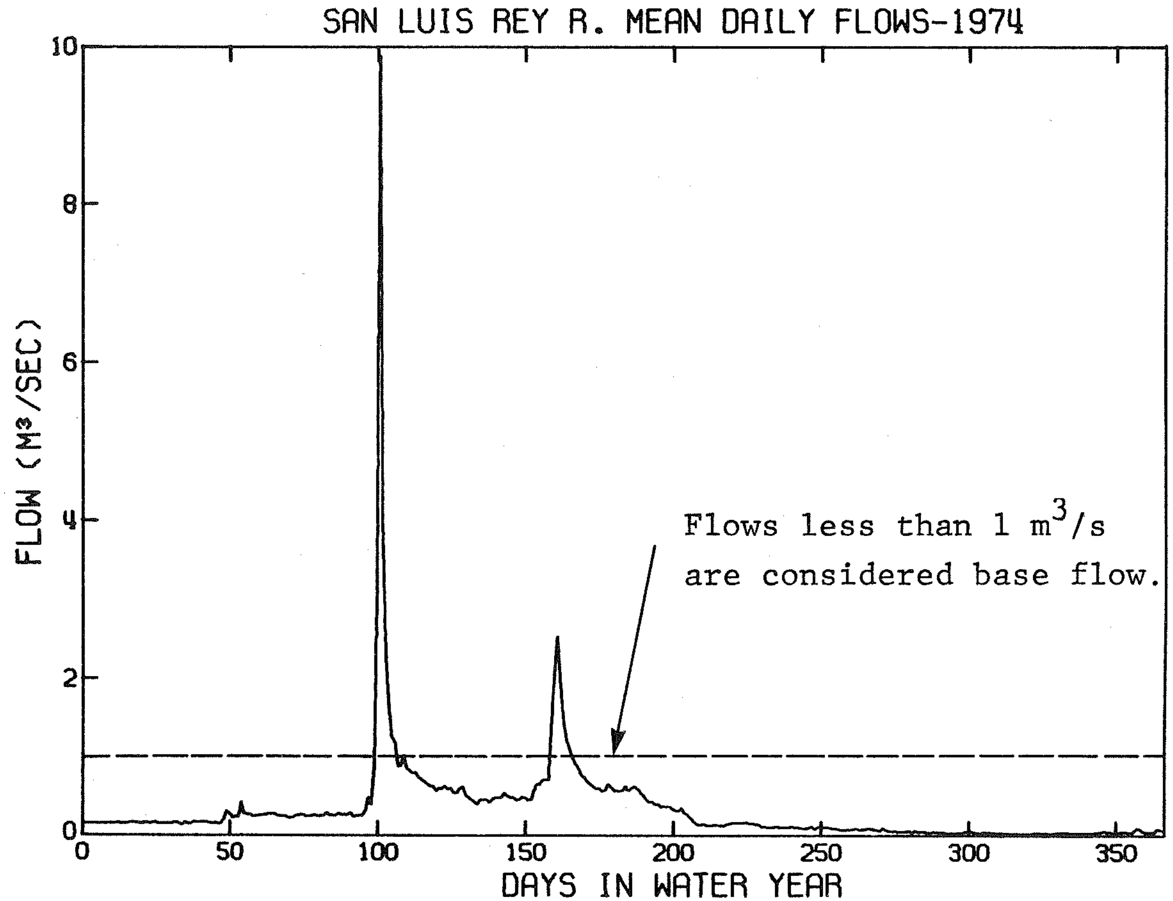

Figure C7-8 Typical annual sequence of mean daily flows (1974 water year) showing chosen cutoff between base flow and storm flows.

where $\hat{\forall}_0(\text{act})$ represents the predicted value of $\forall_0(\text{act})$, and annual flows are given in million m^3. The correlation coefficient between $\forall_0(\text{act})$ and $[\forall_B(\text{act})]^{1.03}$ is 0.996 (see Fig. C7-9).

The percolation correction of 0.8 assumes that losses between the diversion canal and the Oceanside station are 20 percent. This figure assumes that losses between the canal and Oceanside (60 km) are proportional by distance to the losses between Lake Henshaw and the canal (15 km). Losses between Lake Henshaw and the canal are taken to be about 5 percent by the Escondido Mutual Water Company.*

In order to divide natural flows into base and storm flows, it was assumed that base flows under natural conditions would be the same as under actual conditions. Therefore, where sufficient data were available, natural storm flows would be equivalent to total natural flows minus base flows. For the period 1942 through 1946 no daily flow data were available and, therefore, no base flow corrections were made to the total flows for either actual or natural conditions.

C7.8 Annual Suspended Sediment Yield

The total annual suspended sediment yield is a combination of the suspended sediment yield produced by base flows and storm flows. Where sufficient data were available, these quantities were calculated for actual conditions using daily flow data and Eq. C7-1. Having determined natural storm flows, the corresponding natural suspended sediment yields were estimated from Eq. C7-2. Base flow suspended sediment yields for natural conditions were assumed to be the same as for actual conditions. For the period 1942 through 1946 no base flow corrections were made and, therefore, total suspended sediment yields for both natural and actual conditions were made directly from the total flow estimates and Eq. C7-2. The detailed

*EMWC, personal communication, 1978.

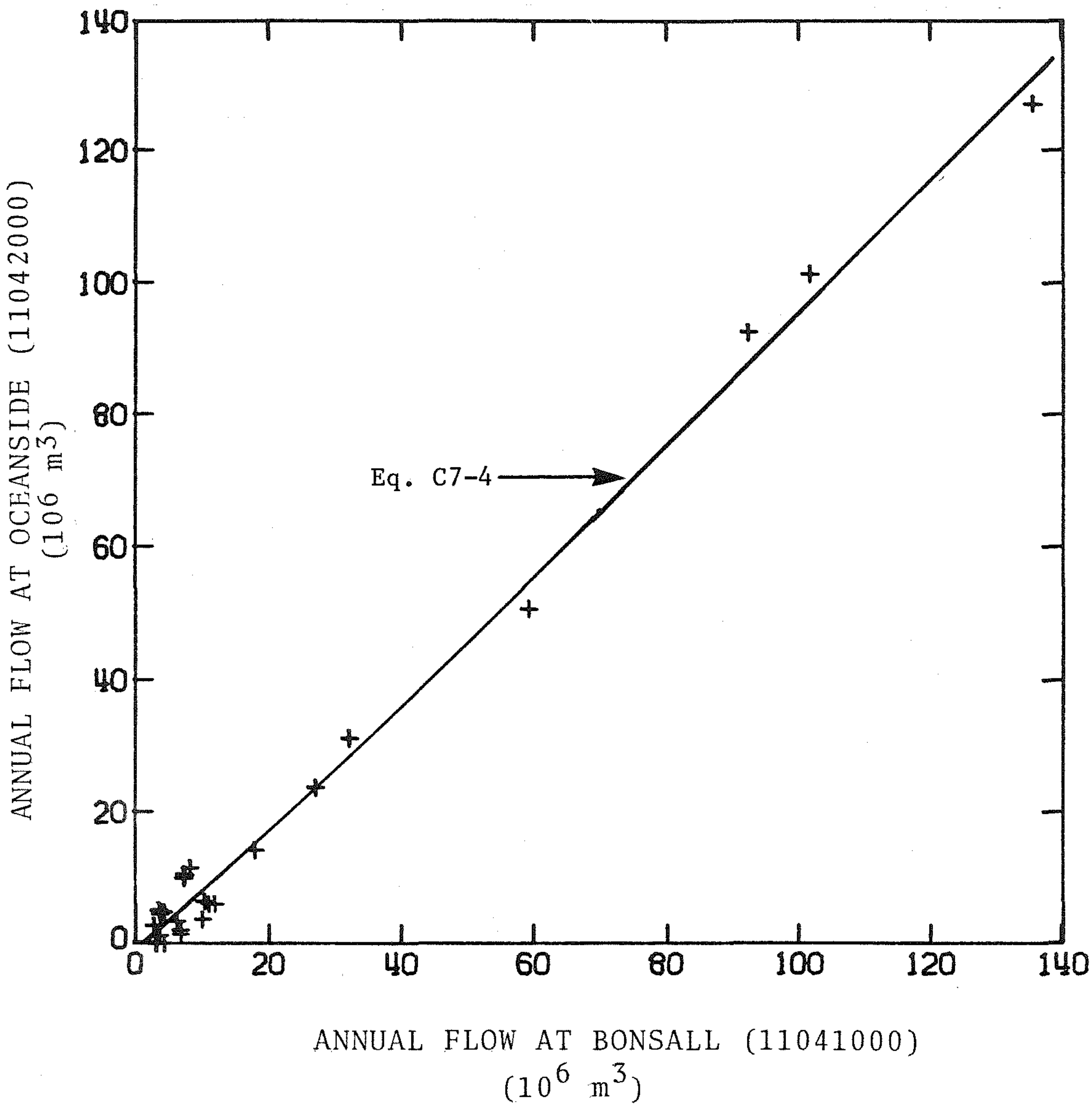

Figure C7-9 Correlation between annual flows at Oceanside and Bonsall, station 1104200 and 11041000, respectively.

Table C7-3
San Luis Rey River (11042000) Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)					ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)				
	1*	2*	3*	1+2	1+3	4*	5*	6*	4+5	4+6
WATER YEAR **	BASE FLOW	STORM ACT FLOW	STORM NAT FLOW	TOTAL ACT FLOW	TOTAL NAT FLOW	BASEFLOW SEDIMENT	STORM ACT SED	STORM NAT SED	TOTAL ACT SED	TOTAL NAT SED
1913 D	1.32	2.69	-1.00	4.02	-1.00	244.09	2615.63	-1.00	2859.72	-1.00
1914 D	2.79	37.08	-1.00	39.88	-1.00	662.94	209841.56	-1.00	210504.50	-1.00
1915-29 X	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930 D	0.81	2.73	21.72	3.55	22.53	189.82	2457.59	59707.18	2647.41	59897.00
1931 N	0.0	0.0	5.41	0.0	5.41	0.0	0.0	7321.45	0.0	7321.45
1932 D	1.98	48.62	100.10	50.60	102.08	362.63	183250.13	557139.25	183612.75	557501.88
1933 D	3.58	2.32	14.52	5.90	18.10	671.26	1072.98	18043.00	1744.25	18714.26
1934 N	0.0	0.0	3.34	0.0	3.34	0.0	0.0	3484.22	0.0	3484.22
1935 D	3.05	3.37	13.30	6.42	16.35	580.42	2612.60	21630.75	3193.02	22211.16
1936 D	1.27	0.63	14.59	1.89	15.86	220.25	270.55	34505.41	490.80	34725.66
1937 D	2.08	125.05	220.70	127.13	222.78	516.69	762458.75	1828479.00	762975.44	1828995.00
1938 D	2.18	90.22	167.79	92.40	169.97	430.44	1032041.56	2682621.00	1032472.00	2683051.00
1939 D	1.48	22.29	49.59	23.77	51.07	302.43	15450.59	52916.90	15753.02	53219.32
1940 D	3.41	10.66	30.87	14.07	34.28	765.16	8114.56	41726.37	8879.73	42491.54
1941 D	2.92	98.57	174.61	101.49	177.53	703.63	257481.63	620958.88	258185.25	621662.50
1942 A	-1.00	-1.00	-1.00	27.16	57.29	-1.00	-1.00	-1.00	87804.13	277081.56
1943 A	-1.00	-1.00	-1.00	40.40	81.14	-1.00	-1.00	-1.00	161822.50	473524.94
1944 A	-1.00	-1.00	-1.00	16.59	44.11	-1.00	-1.00	-1.00	41104.65	185262.31
1945 A	-1.00	-1.00	-1.00	13.63	38.97	-1.00	-1.00	-1.00	30372.27	153087.88
1946 A	-1.00	-1.00	-1.00	12.72	30.64	-1.00	-1.00	-1.00	27306.92	105713.88
1947 N	0.0	0.0	7.76	0.0	7.76	0.0	0.0	12758.91	0.0	12758.91
1948 N	0.0	0.0	4.73	0.0	4.73	0.0	0.0	5953.57	0.0	5953.57
1949 N	0.0	0.0	11.17	0.0	11.17	0.0	0.0	22355.31	0.0	22355.31
1950 N	0.0	0.0	4.65	0.0	4.65	0.0	0.0	5799.24	0.0	5799.24
1951 N	0.0	0.0	1.82	0.0	1.82	0.0	0.0	1368.13	0.0	1368.13
1952 D	0.06	1.21	28.76	1.28	28.82	9.12	1451.53	189738.81	1460.65	189747.88
1953 N	0.0	0.0	4.03	0.0	4.03	0.00	0.0	4652.45	0.00	4652.45
1954 N	0.0	0.0	10.98	0.0	10.98	0.0	0.0	21772.55	0.0	21772.55
1955 N	0.0	0.0	2.02	0.0	2.02	0.0	0.0	1606.36	0.0	1606.36
1956 N	0.0	0.0	1.86	0.0	1.86	0.0	0.0	1414.70	0.0	1414.70
1957 N	0.0	0.0	1.65	0.0	1.65	0.0	0.0	1176.40	0.0	1176.40
1958 D	0.05	3.30	31.35	3.35	31.40	4.45	7385.51	236472.38	7389.96	236476.81
1959 N	0.0	0.0	2.17	0.0	2.17	0.0	0.0	1793.66	0.0	1793.66
1960 N	0.0	0.0	1.92	0.0	1.92	0.0	0.0	1485.57	0.0	1485.57
1961 N	0.0	0.0	0.27	0.0	0.27	0.0	0.0	72.47	0.0	72.47
1962 N	0.0	0.0	3.31	0.0	3.31	0.0	0.0	3436.16	0.0	3436.16
1963 N	0.0	0.0	0.77	0.0	0.77	0.0	0.0	363.85	0.0	363.85
1964 N	0.0	0.0	1.52	0.0	1.52	0.0	0.0	1036.76	0.0	1036.76
1965 N	0.0	0.0	2.69	0.0	2.69	0.0	0.0	2496.80	0.0	2496.80
1966 D	0.54	0.45	10.31	1.00	10.85	40.19	341.28	41924.80	381.47	41964.98
1967 D	0.66	5.24	25.88	5.90	26.54	74.62	27231.60	318144.63	27306.22	318219.19
1968 D	1.96	0.67	3.26	2.63	5.22	150.23	307.43	3489.36	457.66	3639.59
1969 D	3.65	27.58	74.26	31.23	77.91	517.44	162679.88	747607.00	163197.31	748124.44
1970 D	3.10	1.31	4.10	4.40	7.20	194.04	1226.53	7147.50	1420.58	7341.54
1971 D	4.71	0.0	2.05	4.71	6.76	363.72	0.0	1638.31	363.72	2002.02
1972 D	4.81	0.19	1.55	5.00	6.36	384.27	59.26	1549.33	443.54	1933.60
1973 D	7.63	3.81	16.29	11.44	23.92	1048.07	2216.15	20720.51	3264.23	21768.58
1974 D	7.33	3.09	6.23	10.42	13.56	1132.06	2773.64	8150.32	3905.70	9282.38
1975 D	6.13	3.80	7.32	9.92	13.45	860.19	2128.52	5854.06	2988.71	6714.25

*Negative one (-1.00) indicates data unavailable. **See Table C7-4

Table C7-4
San Luis Rey River (11042000)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1930 D	0.00	0.06
1931 N	0.00	0.07
1932 D	0.19	0.62
1933 D	0.19	0.64
1934 N	0.19	0.65
1935 D	0.19	0.67
1936 D	0.19	0.70
1937 D	0.95	2.53
1938 D	1.99	5.22
1939 D	2.00	5.27
1940 D	2.01	5.31
1941 D	2.27	5.93
1942 A	2.36	6.21
1943 A	2.52	6.68
1944 A	2.56	6.87
1945 A	2.59	7.02
1946 A	2.62	7.13
1947 N	2.62	7.14
1948 N	2.62	7.15
1949 N	2.62	7.17
1950 N	2.62	7.17
1951 N	2.62	7.18
1952 D	2.62	7.37
1953 N	2.62	7.37
1954 N	2.62	7.39
1955 N	2.62	7.39
1956 N	2.62	7.40
1957 N	2.62	7.40
1958 D	2.63	7.63
1959 N	2.63	7.63
1960 N	2.63	7.64
1961 N	2.63	7.64
1962 N	2.63	7.64
1963 N	2.63	7.64
1964 N	2.63	7.64
1965 N	2.63	7.64
1966 D	2.63	7.69
1967 D	2.65	8.00
1968 D	2.66	8.01
1969 D	2.82	8.76
1970 D	2.82	8.76
1971 D	2.82	8.76
1972 D	2.82	8.77
1973 D	2.82	8.79
1974 D	2.83	8.80
1975 D	2.83	8.80

*Suspended sand plus washload.
**Actual based on: A - Annual Flows, D - Daily Flows, N - No Flows, X - Missing Data.

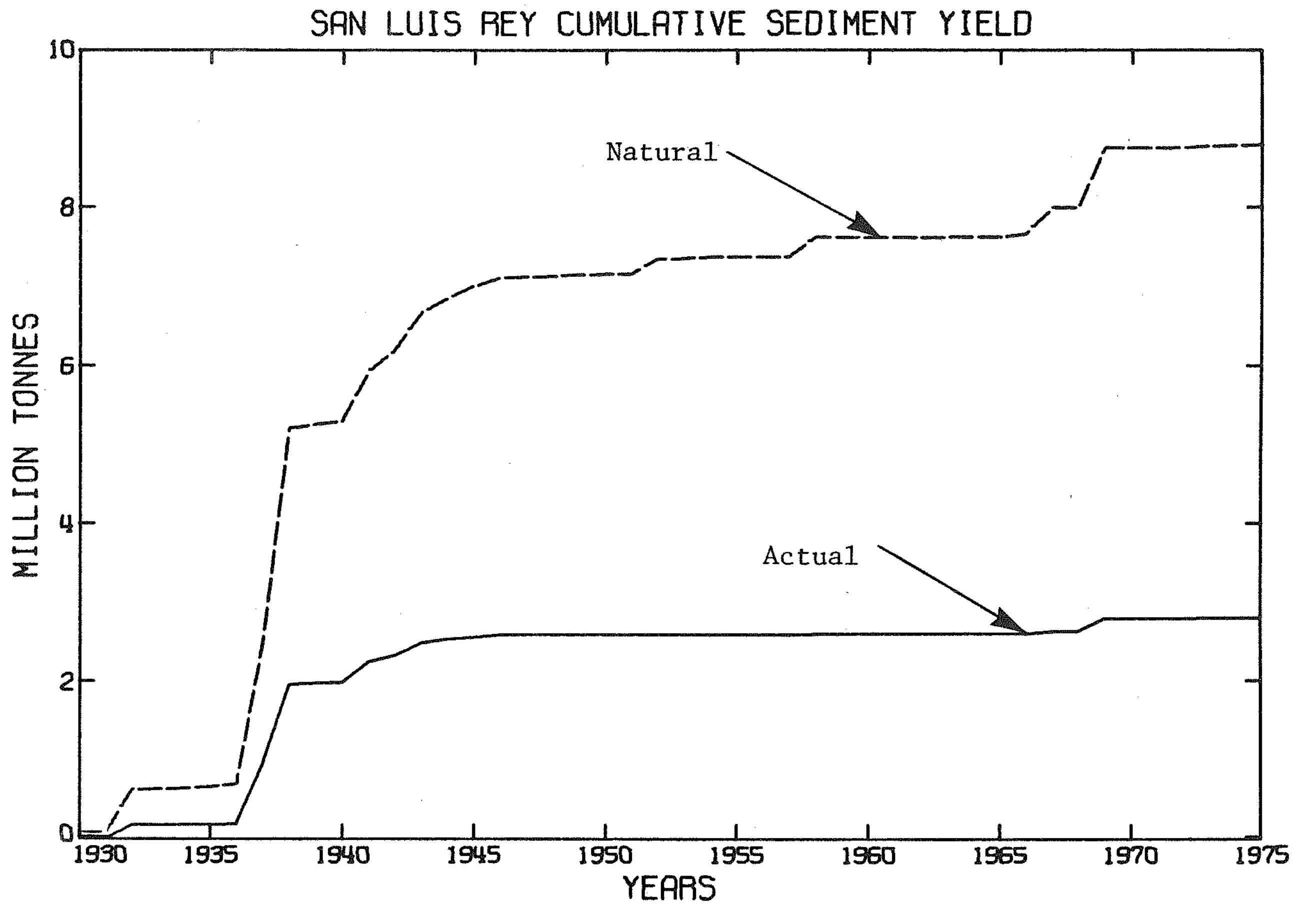

Figure C7-10 Cumulative natural and actual suspended sediment yield at San Luis Rey River station 11042000.

results are given in Table C7-3, and cumulative results are given in Table C7-4 and plotted in Fig. C7-10.

C7.9 Summary

Again, lacking sufficient data, it has been estimated that the suspended load contains, on the average, 25 percent sand and that the ratio of bedload to suspended load is, on the average, 1:10 or 10 percent. Using these figures, average annual sediment yields have been compiled in Table C7-5. The table shows that, for the 46 year period beginning in 1930, the natural average annual yield of sand and gravel has been reduced from about 70,000 tonnes to about 20,000 tonnes, or by a factor of about one third. If these figures are correct, man has created a deficit of 2.08 million tonnes of sand and gravel over the 46 year period.

As a check on the calculations presented herein, the difference between the natural and actual sediment yields can be compared with the accumulation of sediment in Lake Henshaw. A survey of Lake Henshaw in 1951, reported by the Vista Irrigation District*, revealed that the capacity of the reservoir was 239.7 million m^3 (194,300 acre-feet) compared to 246.7 million m^3 (200,000 acre-feet) in 1922, a decrease of 7.0 million m^3 in 29 years. Assuming a dry bulk density of 1.04 tonnes/m^3 (65 lb/ft^3), this decrease represents an average annual accumulation of 250,000 tonnes of sediment. From Table C7-4, the difference between the natural and actual suspended sediment yield for 1930 through 1951 is 4.56 million tonnes. Scaling this figure by 1.1 to include bedload and dividing by 22, the number of years, gives an average annual reduction of the natural sediment yield of 230,000 tonnes (compared to an average annual accumulation of 250,000 tonnes in Lake Henshaw for 1922-1951).

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*John Collins, personal communication, April 1977.

While the results of the calculations compare remarkably well (the yield calculation is 8 percent lower than the reservoir calculation), it should be recalled that these numbers are not expected to agree exactly. For example, the reservoir calculation does not include the effects of channel storage or scour, downstream from the dam.

Table C7-5
San Luis Rey River Average Annual Sediment Yield

Mode of Transport and Sediment Size Class	Annual Sediment Yield in Tonnes: Total Period of Record 1930 - 75		Largest Event 1938 Water Year	
	Actual	Natural	Actual	Natural
Total Suspended Load	61,500	191,000	1,030,000	2,680,000
Suspended Fines (wash load)	46,100	143,000	774,000	2,010,000
Suspended Sand	15,400	47,800	258,000	671,000
Estimated Bedload (sand and gravel)	6,150	19,100	103,000	268,000
Total Sand and Gravel (bed-material load)	21,600	66,900	361,000	939,000
Total Sediment Load	67,700	210,000	1,130,000	2,950,000
Actual Sand Yield / Natural Sand Yield (%)	32%		38%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C8 San Dieguito River Basin

C8.1 Basin Description

The San Dieguito River basin is located in the south of the central portion of the study area (see index map Fig. C8-1). The basin is located within San Diego County and is bounded on the north by the Escondido Creek group and San Luis Rey River basin and on the south by the San Clemente Canyon group and San Diego River basin (Fig. C8-1). Of the 896 km^2 drainage area that makes up the basin, 26 percent of the area is agriculturally developed and 12 percent is urbanized.

The San Dieguito River basin varies greatly in topography and rainfall, with a vegetal cover consisting primarily of coastal sage-brush and chaparral. The eastern and central portions of the basin have low coastal terraces with elevations ranging from sea level to 300 m near Lake Hodges. Precipitation increases from the coast, where the 30 year average (1941-1971) is 28 cm, to Lake Hodges, where the average precipitation is 41 cm. The terrain in the eastern part of the basin is much more rugged, reaching a maximum elevation of 1740 m at Vulcan Mountain, where the annual rainfall averages 56 cm.

C8.2 Geologic Setting

The San Dieguito River drains portions of the Peninsular Ranges province in southern California, flowing across a terrain composed largely of crystalline rocks of the southern California batholith. These rocks include igneous rocks of various granitic composition and those that they intruded over 100 million years ago--Mesozoic and Paleozoic meta-sedimentary and meta-volcanic rocks. These meta-morphosed rocks are concealed along the coastal plain by younger marine sediments of Eocene and Miocene age. Since Pleistocene time,

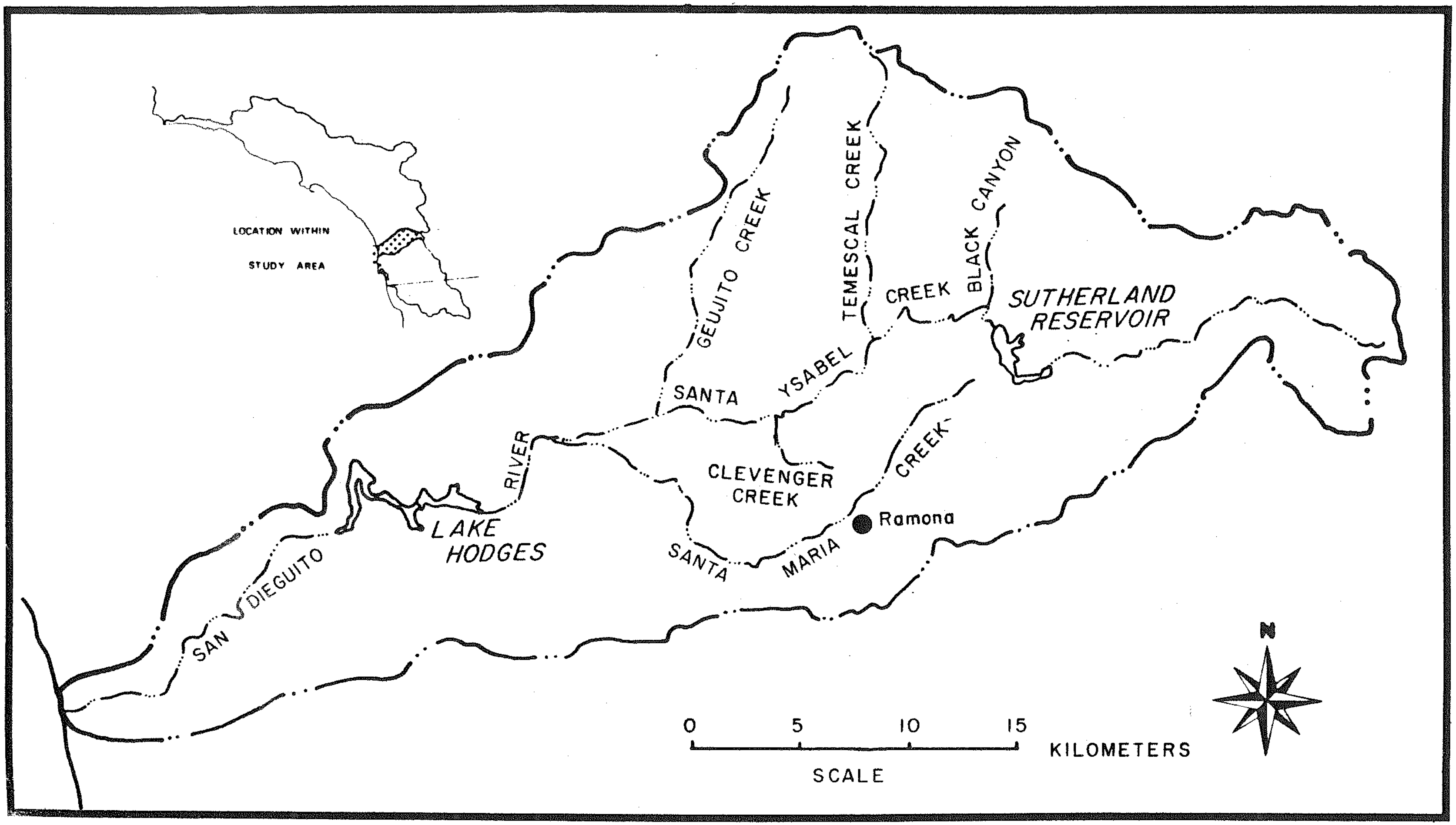

Figure C8-1 San Dieguito River basin.

wave action has cut several terraces in the older rocks along the coast as the coastal region emerged.

Outside of general uplift, tectonic activity has been confined mainly to the Elsinore fault zone to the east and north of the basin. Within the basin, Temescal Creek flows in the Temescal fault valley. The relation between this north trending fault and the northwest-trending Elsinore fault zone is not well understood.

C8.3 Control Facilities

There are two major impoundments on the San Dieguito River basin, Lake Hodges and Sutherland Reservoir. Both are owned by the City of San Diego, and used for municipal water supply. The drainage areas, capacities, and completion dates of the two reservoirs are given in Table C8-1.

C8.4 Gaging Stations

Gaging station locations within the basin are shown in Fig. C8-2 and tabulated in Table C8-2 according to their length of record. The river basin is well gaged for streamflow, both in terms of record lengths and areal coverage. However, there are no sediment gaging stations. Nine of the 19 stations have records of 15 years or more, and only two of the remaining 10 stations are maximum discharge, crest-stage type stations.

C8.5 Stream Bed Characteristics

A sketch of the lower reach of the river is shown in Fig. C8-3. The channel is primarily self-formed, with the major developments being one gravel pit and a few orchards. Also shown on Fig. C8-3 is the San Dieguito Reservoir, which is a holding tank for water from Lake Hodges. Flows at Lake Hodges, 19 km upstream from the mouth, have been used in estimating natural and actual sediment

Table C8-1

Control Structures of the San Dieguito River Basin

Reservoir	Capacity (10^6 m^3)	Completion date	Controlled Drainage Area (km^2)
Lake Hodges	41.4	February 1919	785*
Sutherland Reservoir	36.6	July 1954	140

*Includes area controlled by Sutherland Reservoir since 1954.

NOTE: Total drainage area of the San Dieguito River basin is 896 km^2.

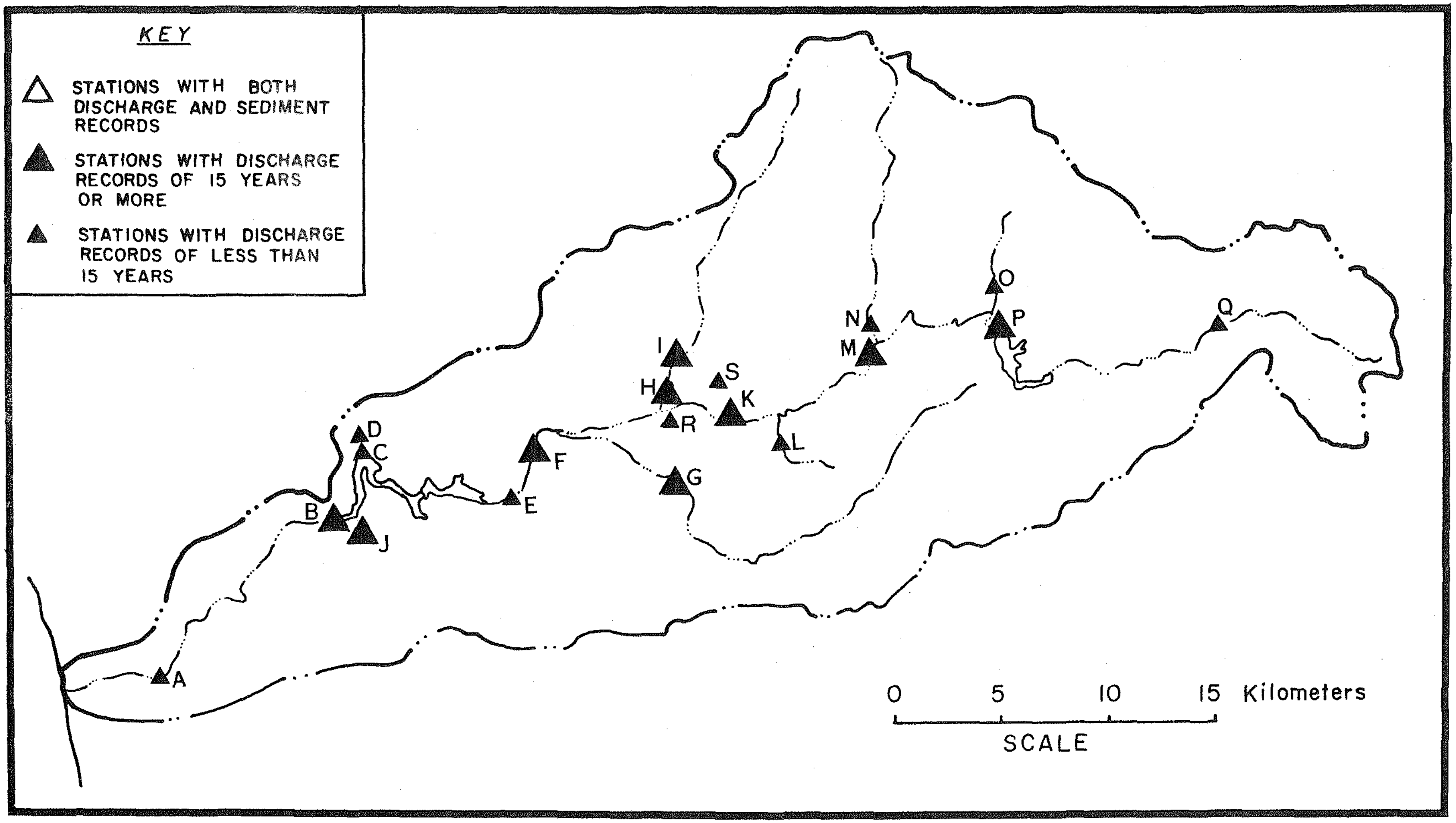

Figure C8-2 Location of streamflow and sediment gaging stations within the San Dieguito River basin.

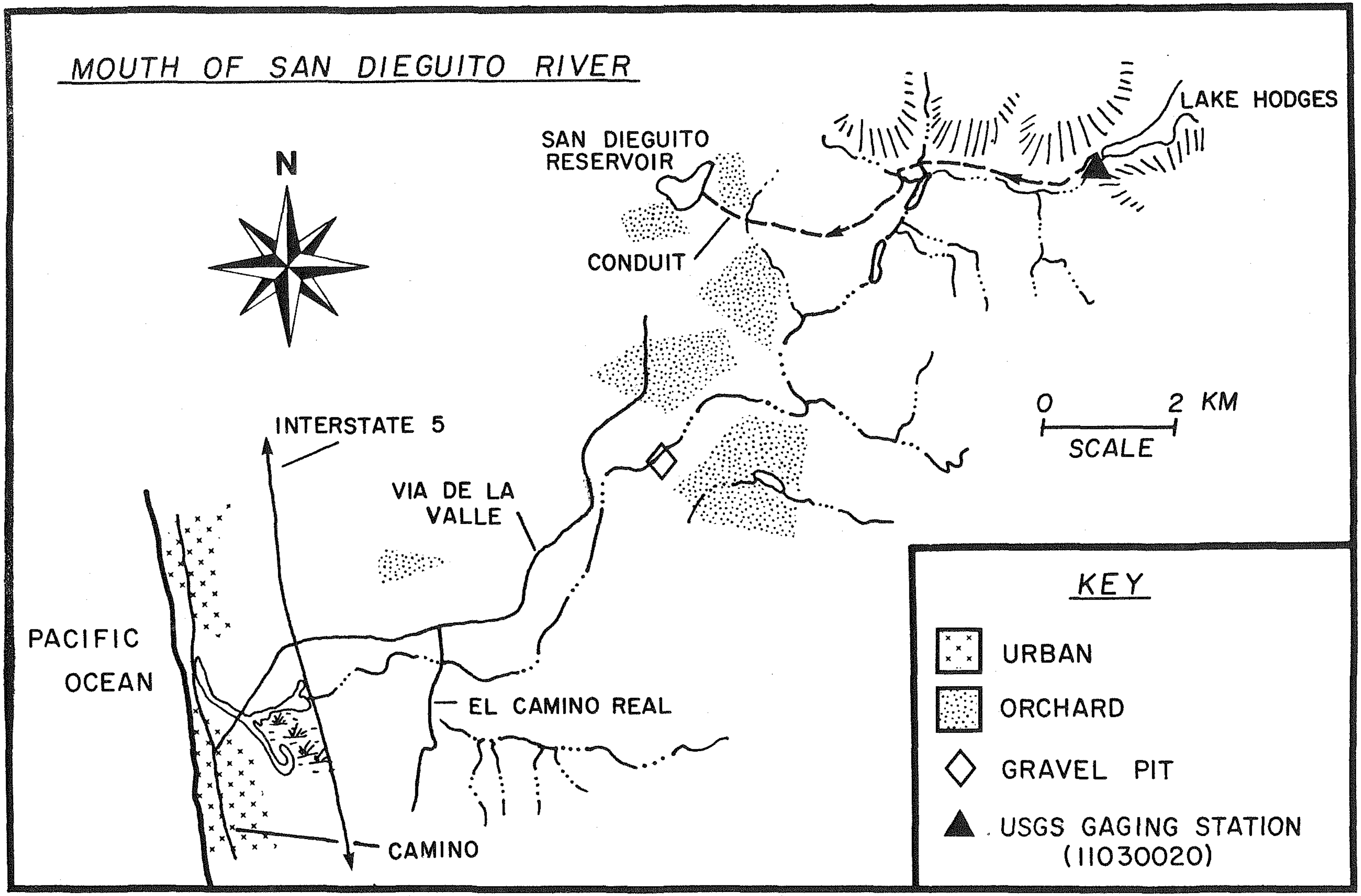

Figure C8-3 Lower **Reach** of the San Dieguito River.

yields from the basin. Since flows at Lake Hodges only represent runoff from 88 percent of the drainage basin, and no correction for flows downstream from Lake Hodges has been included, some error has been introduced.

The bed elevations of the San Dieguito River and two of its tributaries are plotted against distance from the coast in Fig. C8-4. The bed profile of the lower 70 km of the main channel is very similar to that of the San Luis Rey River. For example, the average slope for the lower 40 km of the San Dieguito River is 3.1 m/km compared to 2.9 m/km for the San Luis Rey River.

At this writing, no bed material data are available for the San Dieguito River.

C8.6 Sediment Rating Curve

Although no sediment discharge data have been collected on this basin, a reservoir survey of Lake Hodges, made in 1948 (Belongie and Wong, 1976), indicates total sediment accumulation for the first 29.5 years of reservoir operation. By assuming a trap efficiency for Lake Hodges, a rating curve representing total annual sediment yield was determined.

A trap efficiency of 100 percent was assumed for Lake Hodges, based on a calculation for the minimum expected travel time of a parcel of water passing through the lake. The minimum expected travel time can be calculated by dividing the capacity of the reservoir by the maximum inflow of record. The maximum inflow of record, 156 million m^3 for February 1927, represents a mean daily inflow of 5.57 million m^3. Dividing this figure into the capacity of Lake Hodges, 41.4 million m^3, gives a minimum expected travel time of 7.43 days, which should be sufficient time for almost all of even the finest particles in suspension to settle out. A trap efficiency of 100 percent is not surprising because the reservoir is about 12 km long.

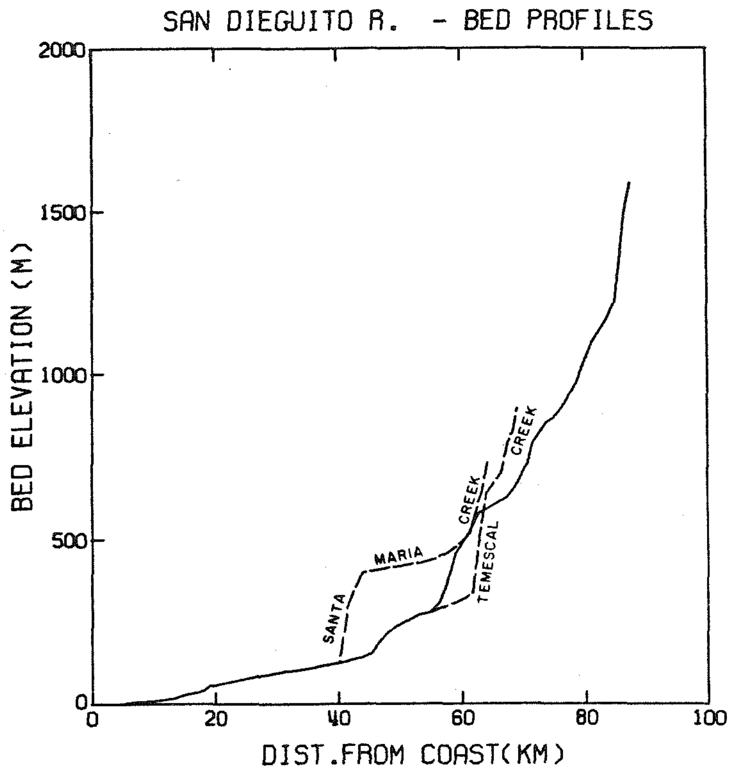

Figure C8-4 Bed profile of the main channel of the San Dieguito River (solid line) and two tributaries (dashed line).

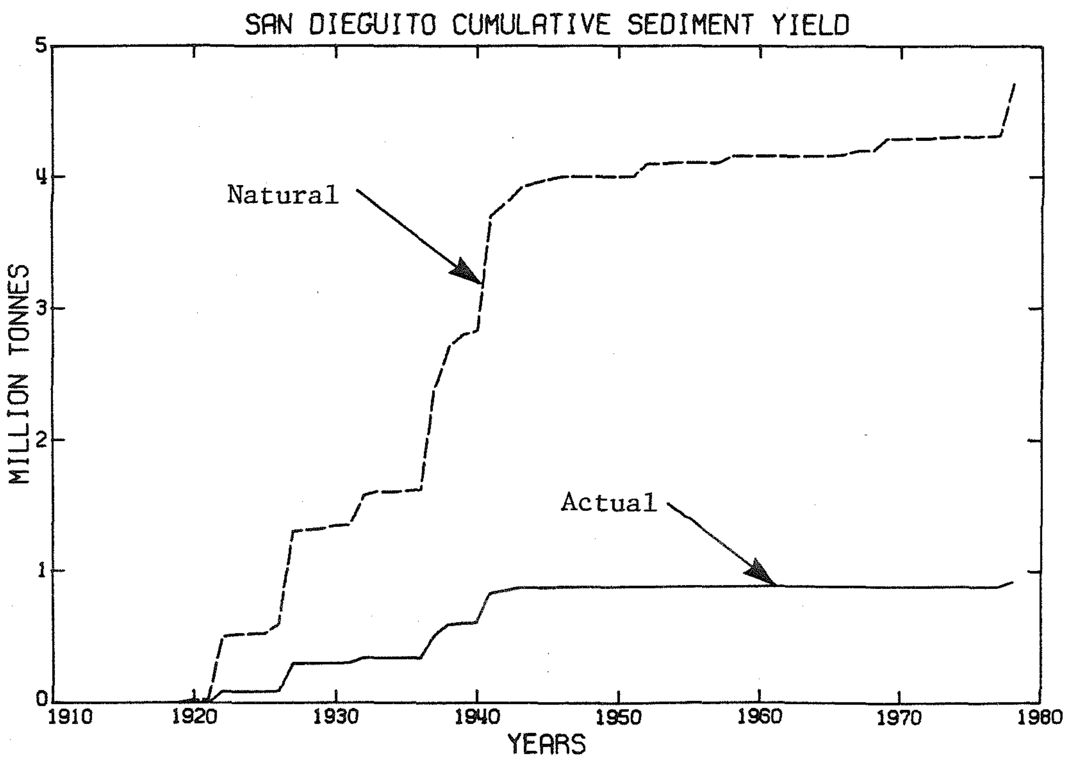

Figure C8-5 Cumulative natural and actual suspended sediment yield at San Dieguito River station 11030020.

The reservoir survey indicates that 4.01 million tonnes of sediment accumulated in 29.5 years. Using this figure and assuming an exponent of 1.5, the following relation was developed.

$$\hat{V}_s = 267\ V^{1.5} \qquad \text{(C8-1)}$$

where $\hat{V}_s$ is the predicted total annual sediment yield, in tonnes, and V is the annual inflow, in million m^3.

C8.7 Estimation of Natural Flows

The effects of Lake Hodges and Sutherland Reservoir on natural flow in San Dieguito River at Lake Hodges, V_H(nat) were estimated from the following equation

$$V_H(\text{nat}) = 0.9[V_{SR}(\text{in}) - V_{SR}(\text{out})] + V_H(\text{in}) \qquad \text{(C8-2)}$$

where 0.9 is a percolation correction, V_{SR}(in) and V_{SR}(out) are the annual Sutherland Reservoir inflows and spills, respectively, and V_H(in) is the annual inflow to Lake Hodges.

The percolation correction, 0.9, a 10 percent loss assumption, is based on the figure used on the San Luis Rey River. The percolation rate used by the Escondido Mutual Water Company between Lake Hodges and their canal (15 km) is 5 percent. Since the distance between Sutherland Reservoir and Lake Hodges is about twice as far (28.5 km), 10 percent was used here.

Values for V_{SR}(in), V_{SR}(out), and V_H(in), as well as actual flows from Lake Hodges (i.e., spills), were obtained from USGS Water Supply Papers, and missing data were obtained from the City of San Diego. All supporting data are given in Section C17.

Table C8-1

Control Structures of the San Dieguito River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
Lake Hodges	41.4	February 1919	785*
Sutherland Reservoir	36.6	July 1954	140

*Includes area controlled by Sutherland Reservoir since 1954.

Note: Total drainage area of the San Dieguito River basin is 896 km^2.

C8.8 Annual Sediment Yield

By taking releases from Lake Hodges as actual flows, and flows from Eq. C8-2 as natural flows, actual and natural total annual sediment yields were determined. For natural sediment yield, Eq. C8-1 was used directly with natural flow data. However, actual sediment yield, which was assumed to be derived from scour of local sediments downstream from Lake Hodges, could not be calculated directly from Eq. C8-1. Such a sediment yield would not be expected to contain much was load (i.e., suspended fines). Therefore, assuming that under natural conditions the average ratio of bedload to suspended load would have been 10 percent and the suspended load would have contained, on the average, 25 percent sand, a factor of 0.318 can be applied to the total load to give the amount of bed material load (suspended sand plus bedload). It is therefore assumed that the total load is completely bed material load under actual conditions, and the actual sediment yield can be estimated using Eq. C8-1 with actual flow data and multiplying the results by 0.318. The annual total sediment yield estimates are given in Table C8-3 and cumulative values are given in Table C8-4 adn plotted in Fig. C8-5.

C8.9 Summary

Actual and natural average annual sediment yields are compiled in Table C8-5 by mode of transport and sediment size class for three time periods. The results show that the combined effects of Lake Hodges and Sutherland Reservoir have drastically reduced the yield of sand and gravel of the San Dieguito River. For the 21 year period beginning with the 1958 water year, the yield of sand and gravel has been reduced to about one fifth what it would have been under natural conditions.

Table C8-2

Gaging Stations within the San Dieguito River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	1X	X4-1120	11-0305.00	SAN DIEGUITO R NR DEL MAR	32-59-54	117-12-12	SDG	5000	SD	1913	1914		G	844.		F
B*	7	X4-1200	11-0300.00	SAN DIEGUITO R A HODGES LK	33-02-48	117-03-30	SDG	5000	SD	1916	1968		G	785.		F
C	7	X4-1210	11-0300.20	HODGES LK NR ESCONDIDO	33-02-41	117-07-39	SDG	5000	SD	1972			E	785.		F
D	3X	X4-1220	11-0298.00	HODGES LK TRIB NR ESCONDIDO	33-05-18	117-06-48	SDG	5000	SD	1961	1973		G	0.47		F
E	1	X4-1260	11-0295.00	SAN DIEGUITO R A BERNARDO	33-03-24	117-03-48	SDG	5000	SD	1912	1916		G	697.		F
F*	2	X4-1320	11-0290.00	SAN DIEGUITO R NR SAN PASQUAL	33-04-00	117-02-06	SDG	5000	SD	1947	1966		G	645.		F
G*	1	X4-1400	11-0285.00	SANTA MARIA C NR RAMONA	33-03-06	116-56-42	SDG	5000	SD	1912		26	G	149.		F
H*	1	X4-1535	11-0275.00	GUEJITO C A SAN PASQUAL	33-05-42	116-57-36	SDG	5000	SD	1915	1956	28	P	71.7		F
I*	1	X4-1620	11-0270.00	GUEJITO C NR SAN PASQUAL	33-06-54	116-57-18	SDG	5000	SD	1946			G	58.3		F
J*	6	X4-1950	11-0300.50	SAN DIEGUITO COND BL HODGES DAM	33-02-48	117-07-30	SDG	5000	SD	1916	1968		G	785.		F
K*	1	X4-2150	11-0260.00	SANTA YSABEL C NR SAN PASQUAL	33-05-00	116-55-00	SDG	5000	SD	1905		35	G	332.		F
L	3X	X4-2160	11-0258.00	CLEVENGER C TRIB NR RAMONA	33-04-12	116-53-30	SDG	5000	SD	1961	1973		G	1.17		F
M*	1	X4-2210	11-0255.00	SANTA YSABEL C NR RAMONA	33-06-24	116-51-54	SDG	5000	SD	1912		20	G	290.		F
N	5	X4-2290	11-0250.00	TEMESCAL C NR ALMOND	33-07-24	116-51-00	SDG	5000	SD	1913	1915		G	76.7		F
O	1	X4-2390	11-0245.00	BLACK CYN C NR MESA GRANDE	33-08-00	116-47-24	SDG	5000	SD	1913	1924		G	39.6		F
P*	1	X4-2500	11-0240.00	SANTA YSABEL C A SUTHERLAND DAM	33-07-06	116-47-12	SDG	5000	SD	1912	1970	18	G	140.		F
C	5R	X4-2650	11-0235.00	SANTA YSABEL C NR SANTA YSABEL	33-07-36	116-40-42	SDG	5000	SD	1913	1914		G	32.4		F
R	2	X4-2935	11-0280.00	SAN PASQUEL,W,D NR ESCONDIDO	33-05-18	116-57-24	SDG	5000	SD	1912	1915		F			F
S	2	X4-2965	11-0265.00	SAN PASQUAL,E,D NR ESCONDIDO	33-05-30	116-55-24	SDG	5000	SD	1912	1914		F			F

* Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

Table C8-3
San Dieguito River (11030020) Actual vs. Natural

Water Year	ANNUAL WATER FLOW ($10^6 m^3$) Actual Flow	ANNUAL WATER FLOW ($10^6 m^3$) Natural Flow	ANNUAL SUSPENDED SEDIMENT YIELD (TONNES) Actual Sediment	ANNUAL SUSPENDED SEDIMENT YIELD (TONNES) Natural Sediment
1919	0.0	4.24	0.0	2323.09
1920	0.0	17.94	0.0	20256.41
1921	0.0	1.83	0.0	661.08
1922	100.00	145.99	84746.44	470102.75
1923	0.0	19.87	0.0	23607.26
1924	0.04	5.86	0.79	3780.77
1925	0.05	2.14	0.93	831.47
1926	17.11	42.37	5997.78	73494.44
1927	182.43	193.29	208817.75	716145.25
1928	3.04	10.98	449.59	9700.20
1929	0.04	10.48	0.66	9044.36
1930	0.04	19.08	0.66	22208.10
1931	0.03	5.93	0.46	3852.62
1932	60.63	90.13	40006.23	228021.13
1933	6.11	21.32	1280.93	26227.42
1934	0.0	1.91	0.0	704.53
1935	0.0	10.51	0.0	9079.50
1936	0.0	13.63	0.0	13410.54
1937	160.24	200.94	171900.69	759072.50
1938	94.96	112.94	78420.38	319860.25
1939	34.13	49.52	16899.20	92864.44
1940	5.68	22.29	1147.29	28043.97
1941	193.55	221.17	228198.44	876541.31
1942	36.10	48.81	18384.98	90876.38
1943	40.07	57.60	21492.79	116513.75
1944	8.77	27.36	2200.14	38136.81
1945	5.39	21.94	1061.69	27394.67
1946	2.84	19.55	406.03	23035.91
1947	0.02	1.78	0.33	633.51
1948	0.01	0.0	0.13	0.0
1949	0.01	1.42	0.10	452.60
1950	0.01	0.0	0.04	0.0
1951	0.0	0.0	0.0	0.0
1952	6.35	49.34	1354.90	92354.75
1953	0.04	1.89	0.63	695.01
1954	0.02	10.74	0.33	9383.12
1955	0.00	0.76	0.02	178.28
1956	0.00	0.95	0.01	248.17
1957	0.01	1.03	0.04	279.57
1958	0.03	32.47	0.35	49311.77
1959	0.00	1.45	0.03	464.71
1960	0.01	1.15	0.07	330.09
1961	0.01	0.15	0.04	14.95
1962	0.01	1.39	0.04	435.12
1963	0.00	0.35	0.01	55.11
1964	0.00	0.56	0.01	110.54
1965	0.00	1.56	0.00	517.23
1966	0.00	10.54	0.02	9118.21
1967	0.01	21.79	0.13	27114.51
1968	0.00	2.41	0.02	994.62
1969	0.0	48.29	0.0	89435.69
1970	0.0	3.18	0.0	1514.39
1971	0.0	3.15	0.0	1486.75
1972	0.0	1.51	0.0	495.25
1973	0.0	11.97	0.0	11032.00
1974	0.0	5.00	0.0	2980.75
1975	0.0	3.05	0.0	1416.32
1976	0.0	6.44	0.0	4353.70
1977	0.0	4.22	0.0	2314.06
1978	57.61	130.26	37060.89	396190.25

NOTE: Sediment refers to total load. All flows are assumed to be storm flows.

Table C8-4
San Dieguito River (11030020)
Cumulative Sediment* Yields (10^6 Tonnes)

Water Year	Actual	Natural
1919	0.0	0.00
1920	0.0	0.02
1921	0.0	0.02
1922	0.08	0.49
1923	0.08	0.52
1924	0.08	0.52
1925	0.08	0.52
1926	0.09	0.60
1927	0.30	1.31
1928	0.30	1.32
1929	0.30	1.33
1930	0.30	1.35
1931	0.30	1.36
1932	0.34	1.58
1933	0.34	1.61
1934	0.34	1.61
1935	0.34	1.62
1936	0.34	1.63
1937	0.51	2.39
1938	0.59	2.71
1939	0.61	2.81
1940	0.61	2.83
1941	0.84	3.71
1942	0.86	3.80
1943	0.88	3.92
1944	0.88	3.96
1945	0.88	3.98
1946	0.86	4.01
1947	0.88	4.01
1948	0.88	4.01
1949	0.88	4.01
1950	0.88	4.01
1951	0.88	4.01
1952	0.88	4.10
1953	0.88	4.10
1954	0.88	4.11
1955	0.88	4.11
1956	0.88	4.11
1957	0.88	4.11
1958	0.88	4.16
1959	0.88	4.16
1960	0.88	4.16
1961	0.88	4.16
1962	0.88	4.16
1963	0.88	4.16
1964	0.88	4.16
1965	0.88	4.16
1966	0.88	4.17
1967	0.88	4.20
1968	0.88	4.20
1969	0.88	4.29
1970	0.88	4.29
1971	0.88	4.29
1972	0.88	4.29
1973	0.88	4.30
1974	0.88	4.31
1975	0.88	4.31
1976	0.88	4.31
1977	0.88	4.31
1978	0.92	4.71

*Suspended sand plus washload.

Table C8-5

San Dieguito River Average Annual Sediment Yield

Annual Sediment Yield in Tonnes

Mode of Transport and Sediment Size Class	Total Period of Record 1919 - 78		Period of Maximum Control 1958 - 78		Largest Event (1958 - 78) 1978 Water Year	
	Actual	Natural	Actual	Natural	Actual	Natural
Total Suspended Load	11,000	71,400	1,360	26,000	37,100	360,000
Suspended Fines (wash load)	0	53,500	0	19,500	0	270,000
Suspended Sand	11,000	17,900	1,360	6,490	26,500	90,000
Estimated Bedload (sand and gravel)	4,380	7,140	544	2,600	10,600	36,000
Total Sand and Gravel (bed-material load)	15,300	25,000	1,900	9,090	37,100	126,000
Total Sediment Load	15,300	78,500	1,900	28,600	37,100	396,000
$\frac{\text{Actual Sand Yield}}{\text{Natural Sand Yield}}$ (%)	61%		21%		29%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C9 San Diego River Basin

C9.1 Drainage Basin Description

The San Diego River basin is located in the southern portion of the study area (see index map Fig. C9-1). The basin covers an area of 1119 km^2, of which 23 percent is urbanized and 3 percent is agriculturally developed. Compared to the other seven basins with limited development, the San Diego River basin is the most urbanized and least agriculturally developed. The urban areas are concentrated near the mouth of the river. Elevations within the basin average about 600 meters and range up to 1700 meters in the upper reaches. Average annual rainfall (1941-1970) ranges from 81 cm in the Cuyamaca Reservoir area to 23 cm near the mouth of the San Diego River. The vegetation of the area varies from chaparral, which covers 90 percent of the area, to coastal sage scrub, accounting for about 7 percent of the area, to small isolated patches of conifers in the higher elevations.

C9.2 Geologic Setting

The San Diego River drains portions of the Peninsular Ranges province in southern California, flowing across a terrain composed largely of crystalline rocks of the southern California batholith. These include igneous rocks of various granitic compositions and those that they intruded over 100 million years ago, Mesozoic and Paleozoic meta-sedimentary and meta-volcanic rocks. The batholithic rocks are concealed to the west by younger marine sediments of Eocene and Miocene age. More recently, wave action cut several terraces in the older rocks along coastal reaches of the drainage as the area emerged during Pleistocene time.

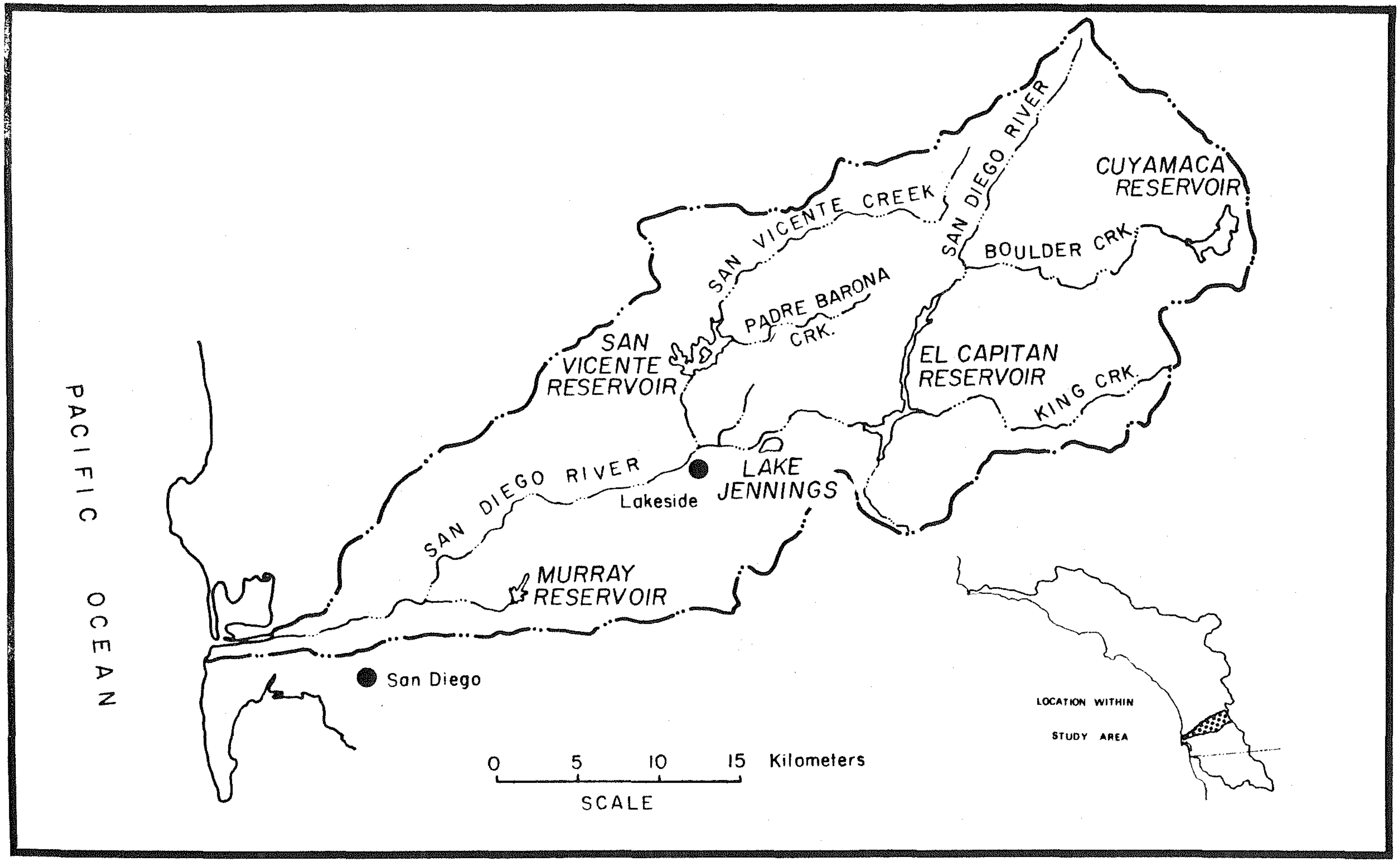

Figure C9-1 San Diego River basin.

Table 9-1

Control Structures of the San Diego River Basin

Reservoir	Capacity (10^6 m^3)	Completion Date	Controlled Drainage Area (km^2)
Cuyamaca	14.2	1884	31.1
Murray	7.50	1918	9.32
El Capitan	139	1935	492*
San Vicente	111	1943	192
Lake Jennings (Chet Harritt Dam)	12.1	1962	4.66

*Includes drainage area controlled by Cuyamaca Reservoir.

NOTE: The total drainage area of the San Diego River basin is 1,119 km^2.

C9.3 Control Facilities

Sixty percent of the total drainage area of the San Diego River is controlled by two major reservoirs: El Capitan Dam on the San Diego River and San Vicente Dam on San Vicente Creek (Fig. C9-1, Table C9-1).

El Capitan Reservoir

El Capitan Dam is owned and operated by the City of San Diego for municipal use and irrigation. This reservoir has had a marked effect on runoff to the ocean since its completion in 1935, as its capacity is large enough to store more than six times the mean annual inflow. The reservoir is also used as a temporary storage for water from the Colorado River aqueduct, but these inflows are released to the water system for San Diego County and do not affect the discharge downstream of the dam. Spills have occurred in only three years since the dam's completion: 1938, 1939, and 1941.

San Vicente Reservoir

San Vicente Dam is also owned and operated by the City of San Diego for municipal use. The capacity of this reservoir is very large, considering its small drainage area and that the dam has never spilled. Colorado River water is also temporarily stored here, as is water diverted from Sutherland Reservoir on Santa Ysabel Creek in the San Dieguito River basin.

Smaller Reservoirs

Besides the two major reservoirs, there are three smaller reservoirs within the San Diego River basin. Cuyamaca Reservoir and Lake Jennings are owned by the Helix Water District and Murray Reservoir is owned by the City of San Diego. Two of these three reservoirs combined only affect 1.2 percent of the drainage area of the San Diego River basin and have not been considered in natural

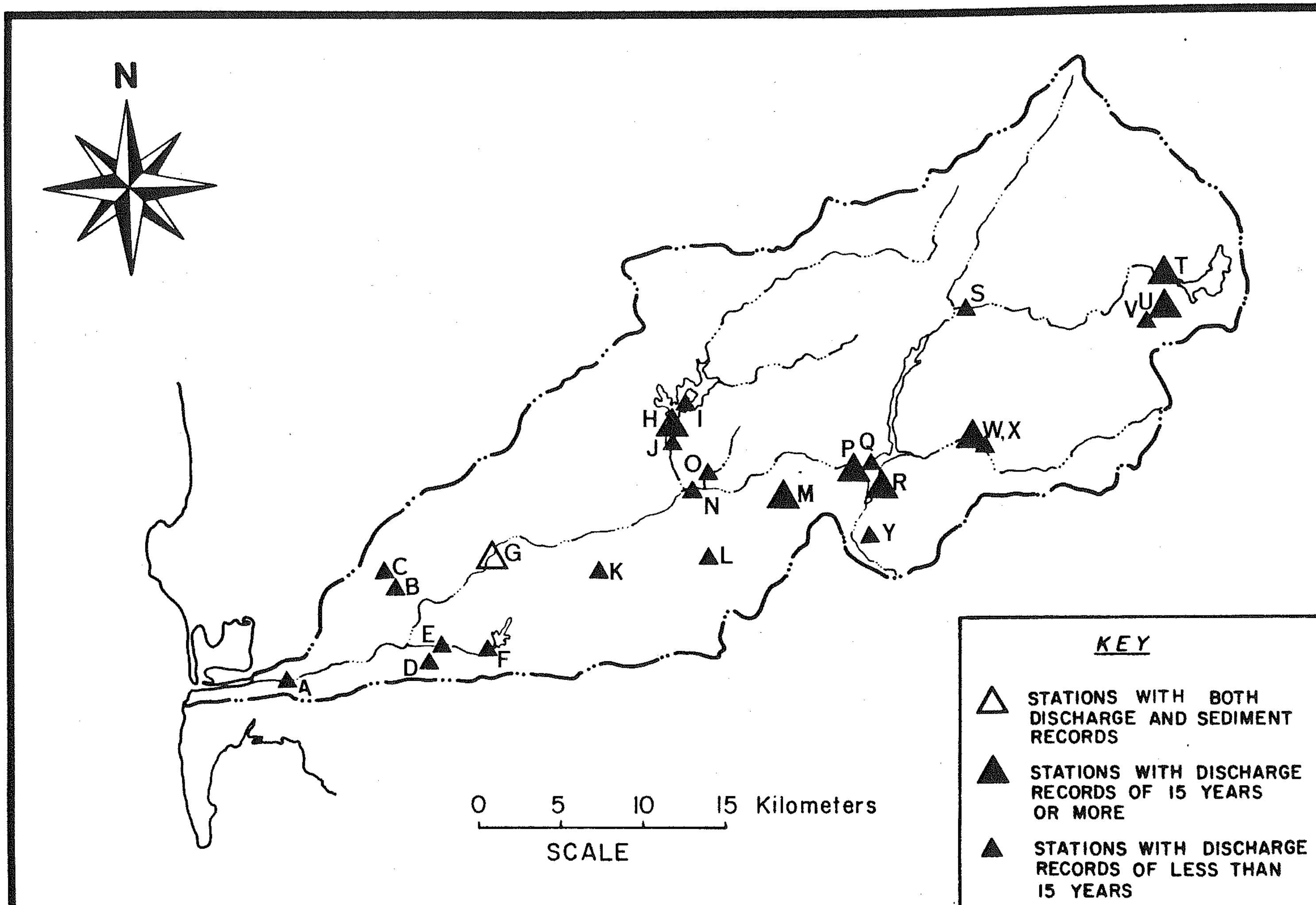

Figure C9-2 Location of streamflow and sediment gaging stations within the San Diego River basin.

Table C9-2
Gaging Stations within the San Diego River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG-MIN-SEC	LONGITUDE DEG-MIN-SEC	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	5	X5-1100	11-0230.00	SAN DIEGO R A SAN DIEGO	32-45-30	117-12-12	SDG	5000	SD	1912	1916		G	1119.		F
B	3X	X5-1135		SHEPHERD CYN C A MURPHY CYN RD	32-49-18	117-06-54	SDG	1401	SD	1965		2	F	7.51		L
C	3X	X5-1140		MURPHY CYN C A CLAIRMONT MESA BLV	32-50-12	117-07-06	SDG	1401	SD	1964		1	G	10.1		L
D	3X	X5-1145		ALVARADO CYN TRIB A I-8 + FAIRMOU	32-46-42	117-06-00	SDG	1401	SD	1964		1	F	7.07		L
E	3X	X5-1150		ALVARADO CYN C A I-8 + WARING RD	32-46-54	117-05-18	SDG	1401	SD	1964			F	22.8		L
F	1	X5-1160	11-0228.00	ALVARADO CYN MURRAY DAM NR LA MES	32-46-48	117-02-48	SDG	5050	SD	1901	1914		P	9.30		S
G*	1	X5-1230	11-0225.00	SAN DIEGO R NR SANTEE	32-49-30	117-03-18	SDG	5000	SD	1912			G	976.		F
H*	5	X5-1320	11-0220.00	SAN VINCENTE C SAN VINCENTE DAM	32-54-42	116-55-36	SDG	5000	SD	1915	1961	19	G	192.		F
I		X5-1325	11-0221.00	SAN VICENTE RES NR LAKESIDE CA	32-54-45	116-55-25	SDG	5000	SD	1972			E	192.		F
J	1	X5-1375	11-0215.00	SAN VINCENTE C NR FOSTER	32-55-24	116-55-12	SDG	5000	SD	1941	1942		G	171.		F
K	1	X5-1380		FORESTER C A CUYAMACA ST	32-49-48	116-59-00	SDG	1401	SD	1965			F	60.6		L
L	1	X5-1415		LOS COCHES CR AT LAKEVIEW RD	32-50-18	116-54-18	SDG	1401	SD	1964			F	35.7		L
M*	3X	X5-1425		BLOSSOM VLY C A FLINN SPR RD	32-51-30	116-51-30	SDG	1401	SD	1963		4	P	3.37		L
N	5	X5-1435	11-0212.00	SAN DIEGO R A LAKESIDE	32-52-18	116-54-54	SDG	5000	SD	1905	1916		G	531.		F
O	3X	X5-1460	11-0211.00	WILDCAT C NR LAKESIDE	32-53-54	116-53-18	SDG	5000	SD	1961	1973		G	2.12		F
P*	1	X5-1520	11-0205.00	SAN DIEGO R A EL CAPITAN DAM	32-53-06	116-48-30	SDG	5000	SD	1936	1966		G	487.		F
Q	1	X5-1530	11-0206.00	EL CAPITAN RES NR LAKESIDE CA	32-53-00	116-48-25	SDG	5000	SD	1972			E	487.		F
R*	1	X5-1600	11-0190.00	SAN DIEGO R A DD NR LAKESIDE	32-58-12	116-44-18	SDG	5400	SD	1912		22	G	262.		F
S	1	X5-1635	11-0175.00	BOULDER C A MOUTH NR LAKESIDE	32-58-36	116-44-00	SDG	5400	SD	1912	1926	3	G	88.1		F
T*	6	X5-1720	11-0170.00	BOULDER C CUYAMACA RES NR JULIAN	32-59-18	116-35-12	SDG	5400	SD	1912	1968		G	31.3		F
U*	6	X5-1930	11-0185.00	CUYAMACA WATER CO FL NR LAKESIDE	32-49-54	116-52-48	SDG	5400	SD	1907	1925		F			F
V	6	X5-1965	11-0180.00	CUYAMACA WATER CO FLUME A DIV DAM	32-58-06	116-44-12	SDG	5400	SD	1912	1924	4	G			F
W*	1	X5-4050		CONEJOS C,SF	32-53-30	116-45-48	SDG	5400	SD	1915			G	114.		SF
X	1	X5-4100	11-0200.00	LOS CONEJOS C NR ALPINE	32-53-12	116-45-30	SDG	5000	SD	1913	1915		G	116.		F
Y	1	X5-4930	11-0195.00	SOUTH FORK FLUME NR ALPINE	32-53-12	116-45-18	SDG	5000	SD	1913	1915		F			F

* Stations with record lengths of 15 years or more. See Section C17 for a complete explanation of codes and abbreviations.

sediment yield calculations. The third reservoir, Cuyamaca, is upstream from El Capitan Dam and its effects have been included with that dam's.

C9.4 Gaging Stations

Gaging station locations within the basin are shown in Fig. C9-2 and listed in Table C9-2 and have been tabulated and illustrated according to their record length. Of the 25 stations listed, only eight have discharge records of 15 years or more. Of the remaining 17 stations, five have records of maximum yearly discharge only, from crest-stage gages.

It is worthwhile to note that the original records kept by the City of San Diego for El Capitan and San Vicente reservoirs vary to some extent from those published by the USGS. It is likely that recalculation of the inflows by the USGS was based on slightly different evaporation-pan coefficients or survey data; however, the differences are not large. Where available, inflows to El Capitan have been taken from USGS records because they include runoff from above Cuyamaca, or such runoff can be included (see supporting data section C19). All other reservoir records were obtained from the City of San Diego.

C9.5 Stream Bed Characteristics

The bed elevation of the San Diego River is plotted against distance from the coast in Fig. C9-3. The average slope in the lower 60 km of the channel is 3.74 m/km. This gentle slope is approximately equal to the lower reaches of the Tijuana and San Dieguito rivers and is the result of the similar gently sloping coastal plain over which all three drain.

The sediment station (11022500), located 20.4 km upstream from the mouth of the San Diego River, within Mission Gorge, represents 87.3 percent of the total drainage area of the basin. The channel

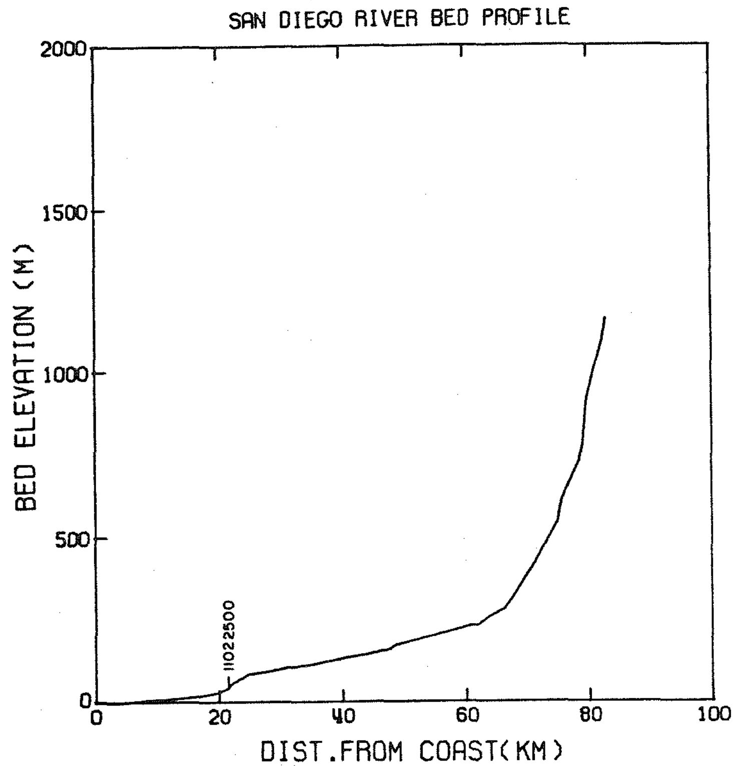

Figure C9-3 Bed profile of the main channel of the San Diego River.

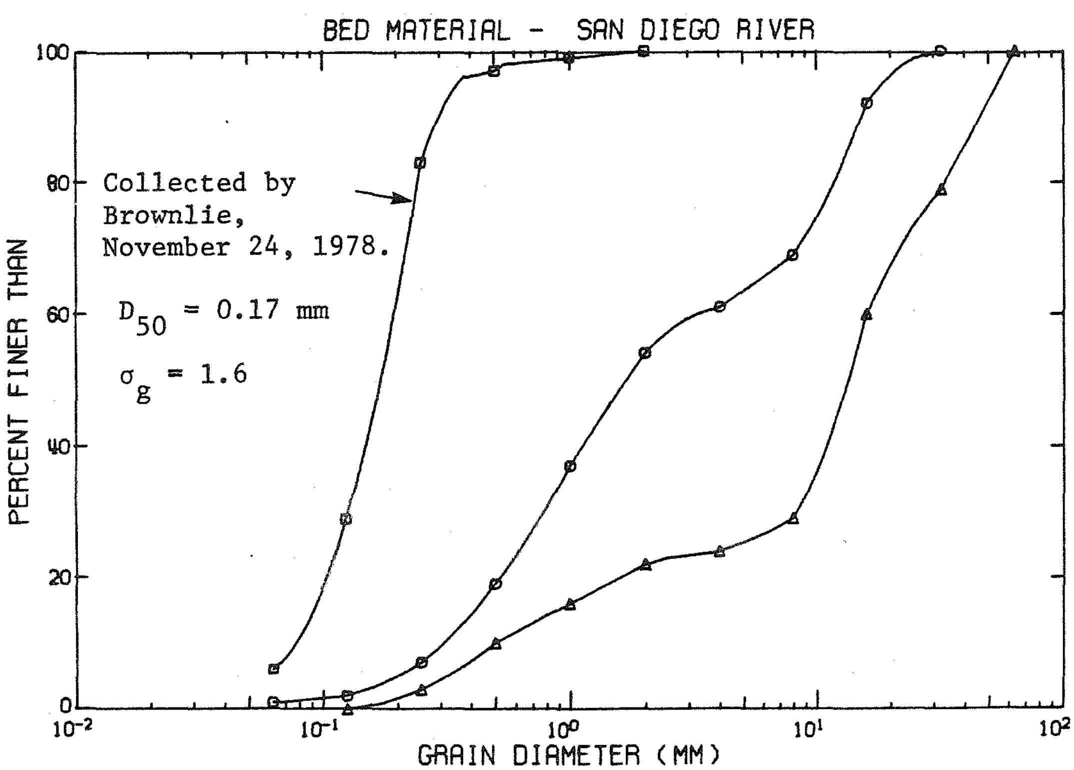

Figure C9-4 Composite surficial bed-material samples collected at 11022500 by the USGS on November 2, 1972, and August 21, 1973, and by Brownlie on November 24, 1978.

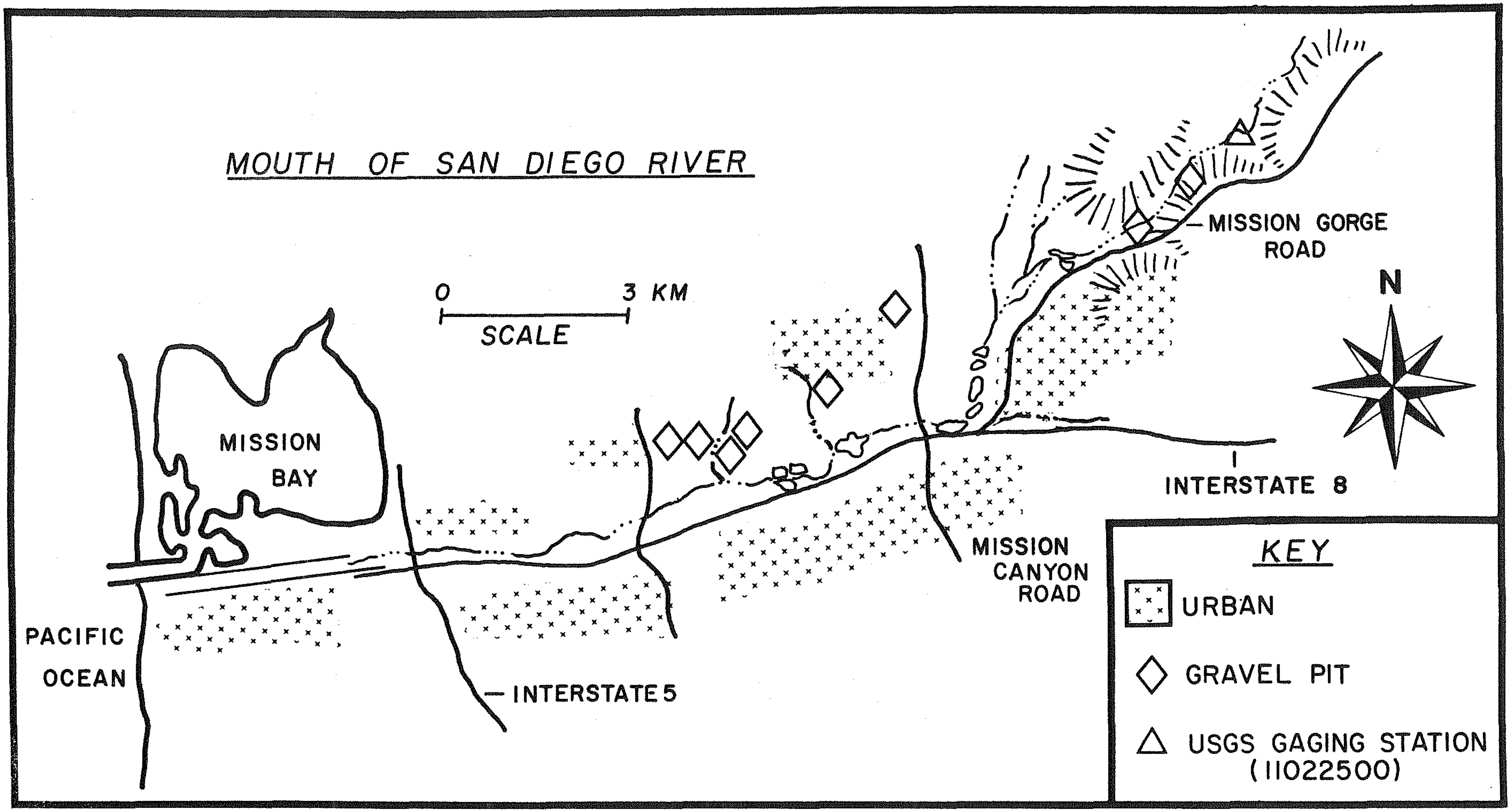

Figure C9-5 Lower reach of the San Diego River.

within the gorge has a steep local slope of 5.61 m/km and is narrow and bounded on both sides by steep cliffs. The surface bed material was measured by the USGS on two dates, November 2, 1972 and August 21, 1973, and by Brownlie on November 24, 1978. The particle-size distributions of the samples are shown in Fig. C9-4. The sample collected by Brownlie has a median diameter of 0.17 mm and a geometric standard deviation of 1.6. The USGS samples were both collected at flows of less than 0.2 m^3/s, and apparently represent an armored bed condition.

The channel 2 km downstream from the sediment station opens onto a floodplain (Fig. C9-5). Percolation basins located along the river bed restrict the flow of the river during low discharge periods. Gravel mining operations lie along both banks of the river below the sediment station.

The only portion of the San Diego River that is channelized is the las few kilometers. The original course of the river into San Diego Bay was permanently altered in 1876 with the construction of a concrete channel, which carries the discharge directly to the ocean, south of the entrance to Mission Bay.

C9.6 Sediment Rating Curve

Actual sediment deliveries for the water years 1913-1915, 1917-1923, and 1926-1969 were estimated from daily streamflow data with the use of an instantaneous sediment rating curve. For those years in which daily streamflow data were unavailable (1914, 1924, 1925) estimates of actual sediment deliveries were made using the relationship of the annual sediment rating curve. Estimates of the annual suspended sediment production for the water years 1970 to 1976 were available from the USGS. The instantaneous rating curve was constructed from 27 USGS published instantaneous suspended sediment concentration data collected between February 6, 1973 and April 13, 1976. The resulting curve, shown in Fig. C9-6, was fitted by the technique described in Section C18.1. The equation for the rating curve is

$$\hat{Q}_{ss} = 8.73\ Q^{1.58} \qquad \text{(C9-1)}$$

where $\hat{Q}_{ss}$ is the predicted suspended sediment discharge in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of Q_s and Q is 0.970.

To determine the sediment yield that would have occurred under natural uncontrolled conditions, a relationship (Fig. C9-7) between annual suspended sediment yield delivered by storms and annual storm flow was needed. From inspection of streamflow records, it was decided that mean daily flows less than 1 m^3/s would be considered to be base flows, and the remaining flows would be considered to be storm flows. (A typical annual streamflow sequence is shown in Fig. C9-8.) The relationship, or annual sediment rating curve, is

$$\hat{\forall}_{ss}(\text{storm}) = 139[\forall(\text{storm})]^{1.43} \qquad \text{(C9-2)}$$

where $\hat{\forall}_{ss}$(storm) is the predicted annual suspended sediment yield produced by storms, in tonnes, and $\forall$(storm) is the annual storm runoff, in million m^3. Equation C9-2, illustrated in Fig. C9-7, was determined by the method described in Section 18.2.

C9.7 Estimation of Natural Flows

Total natural flows at station 11022500 were estimated by considering the effects of San Vicente and El Capitan reservoirs. In equation form, this can be represented as

$$\forall_S(\text{nat}) = \forall_S(\text{act}) + \forall_{SV}(\text{in}) + [\forall_{EC}(\text{in}) - \forall_{EC}(\text{out})] \qquad \text{(C9-3)}$$

where $\forall_S$(nat) and $\forall_S$(act) represent natural and actual annual flows

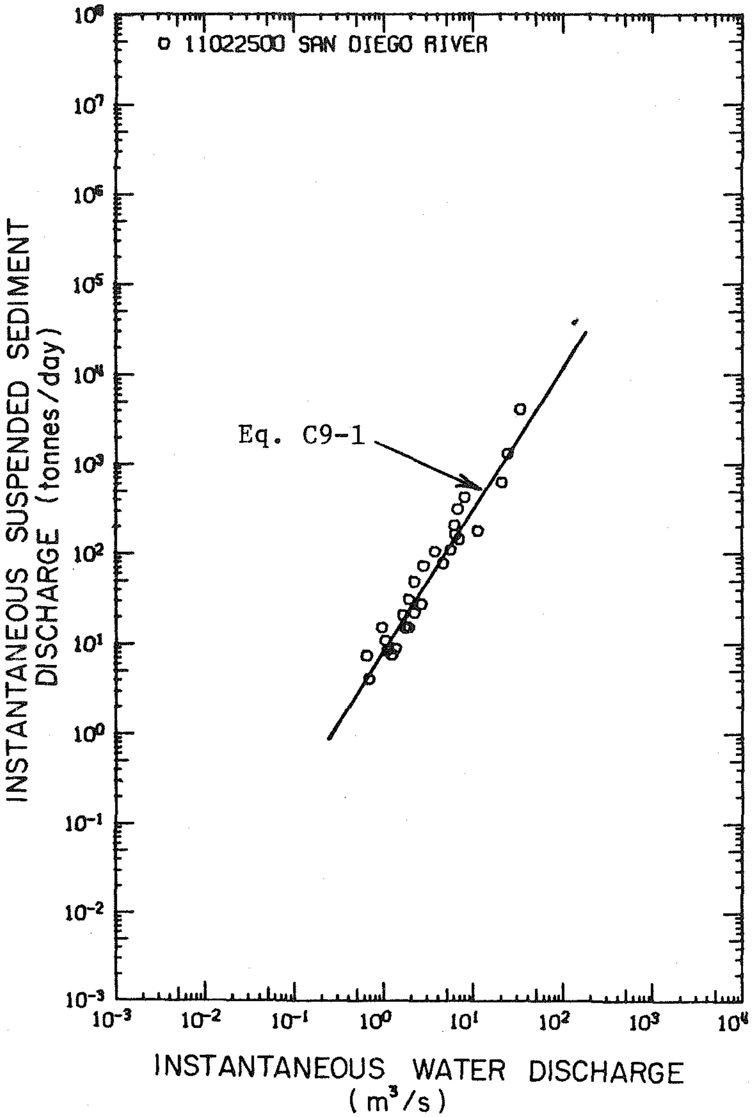

Figure C9-6 Relation of instantaneous sediment discharge to water discharge at San Diego River station 11022500, 1973-76.

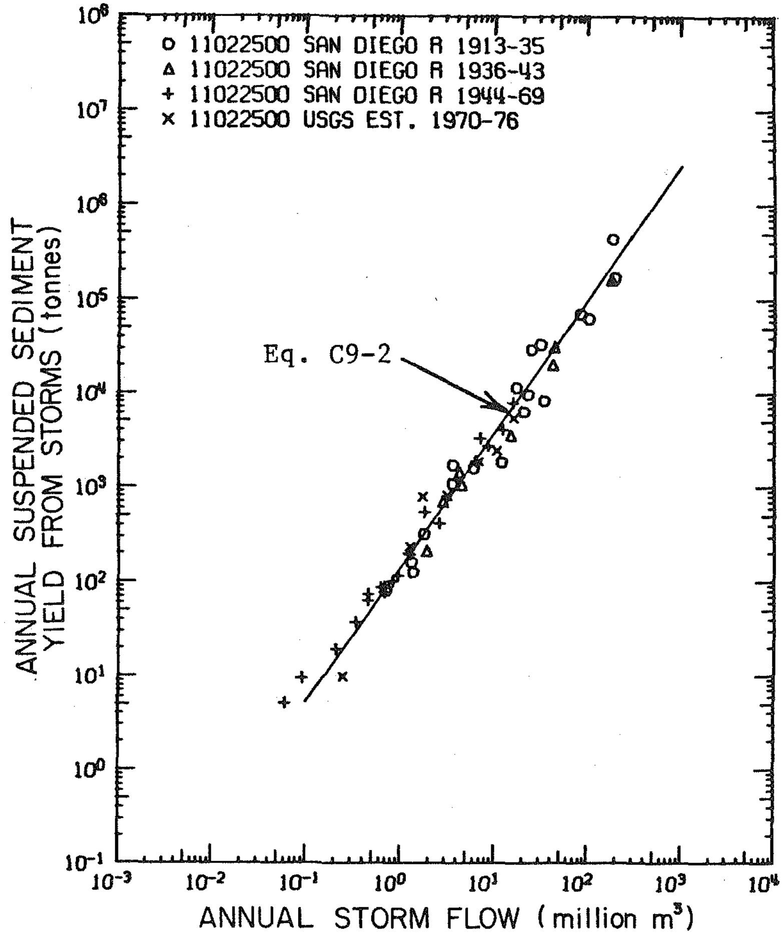

Figure C9-7 Relation of annual suspended sediment delivered by storms to annual storm flows at San Diego River station 11022500, 1913-76.

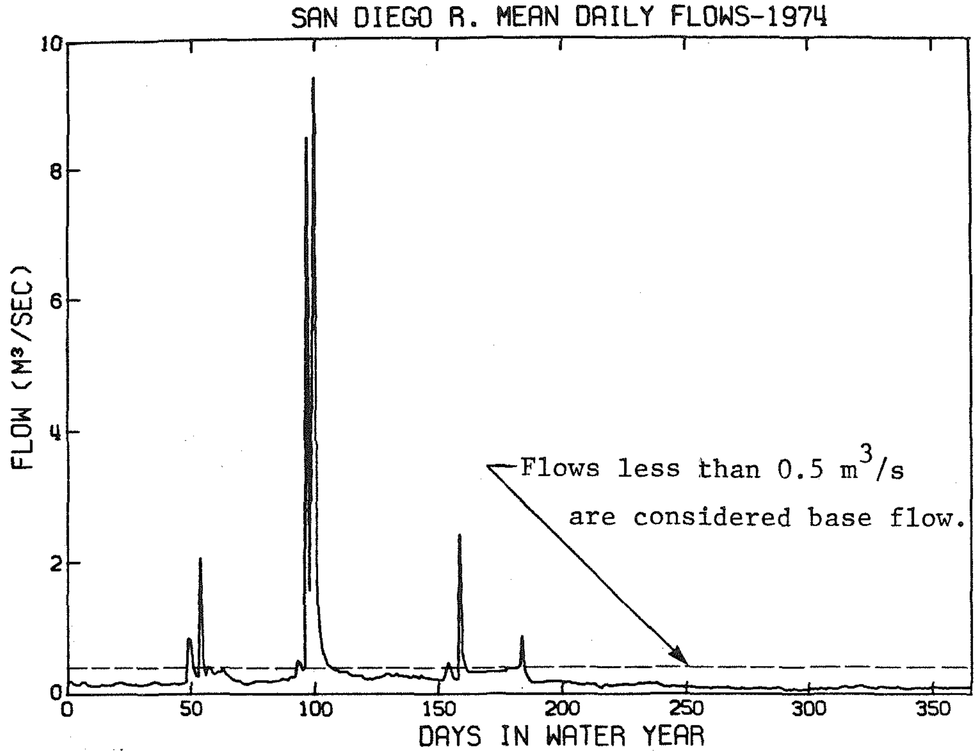

Figure C9-8 Typical annual sequence of mean daily flows (1974 water year) showing chosen cutoff between base flow and storm flow.

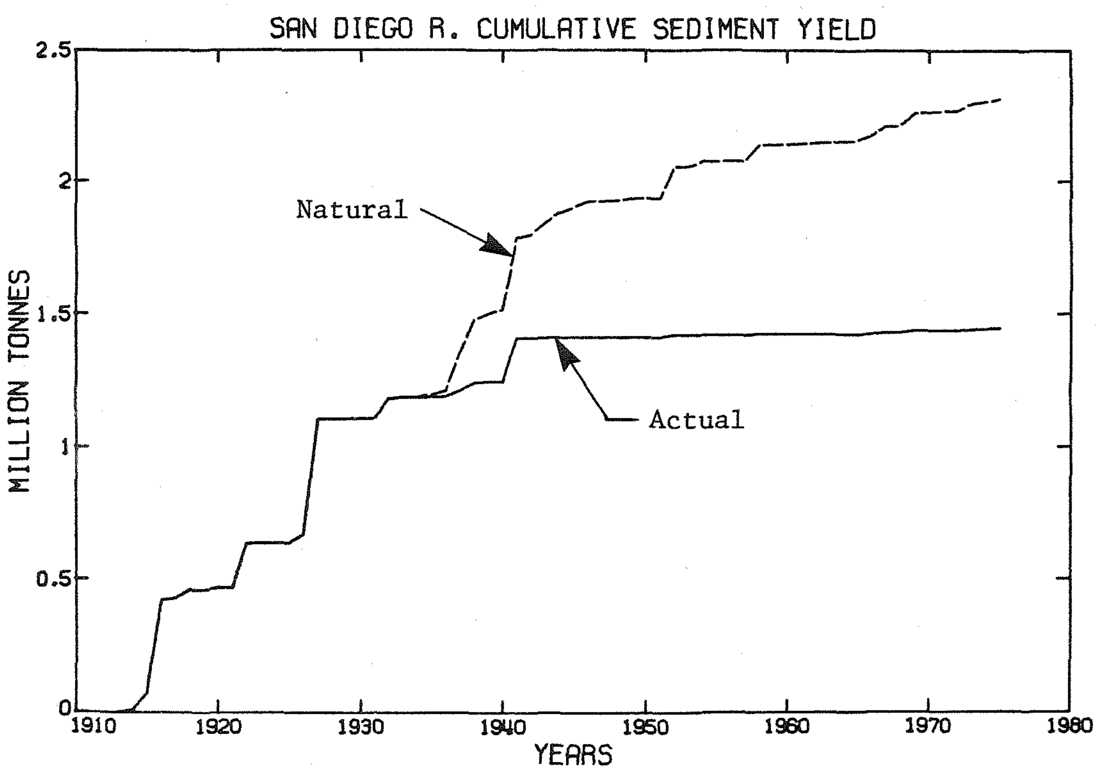

Figure C9-9 Cumulative natural and actual suspended sediment yield at San Diego River station 11022500.

at the station near Santee (11022500), $\forall_{SV}$(in) is the annual inflow to San Vicente Reservoir, and $\forall_{EC}$(in) and $\forall_{EC}$(out) are the annual inflow and spill, respectively, for El Capitan Reservoir. Percolation corrections were neglected, because they were believed to be small, and on the order of various minor diversions which have not been included in the calculation of natural flows.

Natural base flows were believed to be different from actual base flows for the San Diego River due to a noticeable increasing trend in actual annual base flows after 1935, the first year of major control. Prior to 1935, no actual annual base flow was above 1.00 million m^3 (Table C9-3). From 1935 to 1976, actual annual base flows ranged from 0.06 to 5.75 million m^3. This increase appears to be an artifact of upstream controls, perhaps natural seepage from El Capitan Dam.

Natural base flows for the period 1913 to 1935 were equal to the actual base flows. Natural base flows for the 1935 to 1976 period were taken as the average of the actual base flow values from 1913 to 1935. This calculated average of 0.55 million m^3 was assumed to represent the natural annual base flow. The corresponding annual natural suspended sediment yield for 1935 to 1976 was taken as 21 tonnes, determined from the average concentration of 38 mg/l for the 1913 to 1935 period.

C9.8 Suspended Sediment Yield

The predicted actual and natural suspended sediment yields are given in Table C9-3. The cumulative values for actual and natural sediment yields are plotted in Fig. C9-9 and tabulated in Table C9-4.

As can be seen by the cumulative sediment plot, the natural yield (dashed line) and the actual yield (solid line) diverge at 1935. This break corresponds to the completion of El Capitan Dam. For the period 1935 through 1942, El Capitan Dam produced a 55 percent

Table C9-3
San Diego River (11022500)
Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)				ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)					
	1	2	3	4	5	6	7	8	5+7	6+8
WATER YEAR **	ACTUAL BASEFLOW*	NATURAL BASEFLOW*	TOTAL ACT FLOW	TOTAL NAT FLOW	BASEFLOW ACT SED*	BASEFLOW NAT SED*	STORM ACT SED*	STORM NAT SED*	TOTAL ACT SED	TOTAL NAT SED
1913 D	0.75	0.75	2.10	2.10	33.11	33.11	124.80	124.80	157.91	157.91
1914 D	0.64	0.64	17.78	17.78	26.23	26.23	11389.09	11389.09	11415.31	11415.31
1915 D	0.45	0.45	101.79	101.79	21.21	21.21	62895.98	62895.98	62917.20	62917.20
1916 A	-1.00	-1.00	241.00	241.00	-1.00	-1.00	-1.00	-1.00	347756.13	347756.13
1917 D	0.48	0.48	34.51	34.51	22.19	22.19	8218.46	8218.46	8240.65	8240.64
1918 D	0.41	0.41	25.23	25.23	14.04	14.04	29217.91	29216.21	29231.95	29230.25
1919 D	0.58	0.58	1.88	1.88	19.55	19.55	159.51	159.51	179.06	179.06
1920 D	0.63	0.63	23.68	23.68	26.76	26.76	9531.81	9531.81	9558.57	9558.57
1921 D	0.22	0.22	0.22	0.22	2.65	2.65	0.0	0.0	2.65	2.65
1922 D	0.21	0.21	195.52	195.52	6.44	6.44	170190.06	170190.06	170196.50	170196.50
1923 D	0.52	0.52	12.46	12.46	22.93	22.93	1821.56	1821.56	1844.49	1844.49
1924 A	-1.00	-1.00	0.09	0.09	-1.00	-1.00	-1.00	-1.00	4.47	4.47
1925 A	-1.00	-1.00	0.18	0.18	-1.00	-1.00	-1.00	-1.00	12.01	12.01
1926 D	0.43	0.43	31.92	31.92	13.75	13.75	33271.78	33273.27	33285.53	33287.02
1927 D	0.58	0.58	183.33	183.33	24.63	24.63	432216.38	432213.00	432241.00	432237.63
1928 D	0.78	0.78	1.48	1.48	31.58	31.58	80.86	80.86	112.44	112.44
1929 D	0.31	0.31	2.10	2.10	8.87	8.87	316.98	316.98	325.85	325.85
1930 D	0.63	0.63	6.67	6.67	18.97	18.97	1571.05	1571.05	1590.02	1590.02
1931 D	0.68	0.68	4.29	4.29	24.24	24.24	1695.16	1695.16	1719.40	1719.40
1932 D	0.91	0.91	83.81	83.81	40.31	40.31	69956.31	69956.31	69996.63	69996.63
1933 D	0.83	0.83	21.47	21.47	36.54	36.54	6244.52	6244.52	6281.06	6281.06
1934 D	0.06	0.06	0.06	0.06	0.30	0.30	0.0	0.0	0.30	0.30
1935 D	0.79	0.79	4.32	17.38	25.96	25.96	1071.66	9752.14	1097.61	9778.10
1936 D	0.66	0.55	4.91	21.51	18.63	21.00	1411.74	13758.31	1430.38	13779.31
1937 D	1.08	0.55	42.83	169.30	44.47	21.00	20114.14	147613.81	20158.61	147634.81
1938 D	0.62	0.55	44.61	113.51	23.15	21.00	31390.92	120549.13	31414.07	120570.13
1939 D	1.28	0.55	16.16	53.92	62.79	21.00	3522.69	21801.12	3585.48	21822.12
1940 D	1.23	0.55	4.04	27.46	47.76	21.00	696.85	17502.74	744.61	17523.74
1941 D	0.59	0.55	180.09	254.12	45.94	21.00	163348.94	268278.75	163394.88	268299.75
1942 D	2.38	0.55	4.26	36.52	106.38	21.00	211.00	14172.12	317.38	14193.12

*Negative one (-1.00) indicates data are unavailable.
**See Table C9-4 for abbreviations after year.

Table C9-3 (cont.)
San Diego River (11022500)
Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m^3)				ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)					
	1	2	3	4	5	6	7	8	5+7	6+8
WATER YEAR**	ACTUAL BASEFLOW	NATURAL BASEFLOW	TOTAL ACT FLOW	TOTAL NAT FLOW*	BASEFLOW ACT SED	BASEFLOW NAT SED	STORM ACT SED	STORM NAT SED*	TOTAL ACT SED	TOTAL NAT SED*
1943 D	1.51	0.55	6.02	61.55	66.14	21.00	1039.41	42701.09	1105.55	42722.09
1944 D	1.47	0.55	7.84	54.69	50.01	21.00	1857.55	39444.62	1907.55	39465.62
1945 D	1.26	0.55	1.93	34.94	39.90	21.00	76.11	20775.81	116.01	20796.81
1946 D	1.17	0.55	2.99	25.38	41.27	21.00	535.85	22262.80	577.12	22283.80
1947 D	0.06	0.55	0.06	7.54	0.32	21.00	0.0	2222.55	0.32	2243.55
1948 D	0.25	0.55	0.70	4.07	5.07	21.00	62.82	1173.45	67.89	1194.45
1949 D	1.02	0.55	1.97	18.67	37.48	21.00	114.95	7757.01	152.43	7778.01
1950 D	0.08	0.55	0.08	6.57	1.78	21.00	0.0	1796.24	1.78	1817.24
1951 D	0.00	0.55	0.00	3.28	0.01	21.00	0.0	582.86	0.01	603.86
1952 D	1.37	0.55	17.29	104.48	53.95	21.00	7832.03	113871.94	7885.98	113892.94
1953 D	0.25	0.55	0.25	7.72	3.76	21.00	0.0	2307.29	3.76	2328.29
1954 D	0.58	0.55	4.58	28.32	21.32	21.00	1192.00	18959.64	1213.32	18980.64
1955 D	0.35	0.55	0.44	3.97	7.85	21.00	9.40	1659.31	17.25	1680.31
1956 D	0.18	0.55	0.24	2.57	3.61	21.00	5.06	744.72	8.66	765.72
1957 D	0.47	0.55	0.81	5.52	12.49	21.00	37.07	1716.15	49.56	1737.15
1958 D	1.49	0.55	10.05	75.02	46.48	21.00	2696.49	59037.73	2742.97	59058.73
1959 D	1.20	0.55	1.90	5.68	27.83	21.00	87.50	1524.82	115.33	1545.82
1960 D	2.68	0.55	3.51	7.93	80.65	21.00	100.80	2249.54	181.45	2270.54
1961 D	2.77	0.55	2.98	4.72	76.06	21.00	19.20	1384.92	95.26	1405.92
1962 D	4.34	0.55	6.97	13.99	158.24	21.00	407.21	4174.73	565.45	4195.73
1963 D	3.75	0.55	4.20	6.05	121.52	21.00	73.67	2578.31	195.19	2599.31
1964 D	0.83	0.55	1.46	8.66	20.79	21.00	87.02	3305.69	107.81	3326.69
1965 D	0.97	0.55	2.20	9.96	30.48	21.00	195.31	3560.94	225.79	3581.94
1966 D	1.94	0.55	14.23	37.85	83.58	21.00	3995.34	19473.69	4078.92	19494.69
1967 D	2.34	0.55	9.45	37.88	87.25	21.00	3264.42	34760.49	3351.66	34781.49
1968 D	0.96	0.55	2.23	5.42	24.89	21.00	191.38	1303.17	216.27	1324.17
1969 D	1.85	0.55	17.94	75.33	67.52	21.00	5364.34	48050.30	5431.86	48071.30
1970 U	1.55	0.55	3.27	7.22	117.80	21.00	778.40	5365.73	896.20	5386.73
1971 U	4.47	0.55	4.71	11.38	92.30	21.00	9.70	2138.13	102.00	2159.13
1972 U	3.77	0.55	5.04	7.84	161.20	21.00	234.50	2839.63	395.70	2860.63
1973 U	5.33	0.55	12.14	42.85	230.90	21.00	1859.90	25179.27	2090.80	25200.27
1974 U	5.63	0.55	8.73	16.46	160.70	21.00	807.20	8332.31	967.90	8353.31
1975 U	5.75	0.55	16.31	27.47	178.30	21.00	2407.20	9155.83	2585.50	9176.83
1976 U	3.96	0.55	8.94	-1.00	96.90	21.00	1365.00	-1.00	1461.90	-1.00

*Negative one (-1.00) indicates data are unavailable.
**See Table C9-4 for abbreviations used after the year.

Table C9-4
San Diego River (11022500)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1913 D	0.00	0.00
1914 D	0.01	0.01
1915 D	0.07	0.07
1916 A	0.42	0.42
1917 D	0.43	0.43
1918 D	0.46	0.46
1919 D	0.46	0.46
1920 D	0.47	0.47
1921 D	0.47	0.47
1922 D	0.64	0.64
1923 D	0.64	0.64
1924 A	0.64	0.64
1925 A	0.64	0.64
1926 D	0.67	0.67
1927 D	1.11	1.11
1928 D	1.11	1.11
1929 D	1.11	1.11
1930 D	1.11	1.11
1931 D	1.11	1.11
1932 D	1.18	1.18
1933 D	1.19	1.19
1934 D	1.19	1.19
1935 D	1.19	1.20
1936 D	1.19	1.21
1937 D	1.21	1.36
1938 D	1.24	1.48
1939 D	1.24	1.50
1940 D	1.25	1.52
1941 D	1.41	1.79
1942 D	1.41	1.80
1943 D	1.41	1.84
1944 D	1.41	1.88
1945 D	1.41	1.90
1946 D	1.41	1.93
1947 D	1.41	1.93
1948 D	1.41	1.93
1949 D	1.41	1.94
1950 D	1.41	1.94
1951 D	1.41	1.94
1952 D	1.42	2.05
1953 D	1.42	2.06
1954 D	1.42	2.07
1955 D	1.42	2.08
1956 D	1.42	2.08
1957 D	1.42	2.08
1958 D	1.43	2.14
1959 D	1.43	2.14
1960 D	1.43	2.14
1961 D	1.43	2.14
1962 D	1.43	2.15
1963 D	1.43	2.15
1964 D	1.43	2.15
1965 D	1.43	2.16
1966 D	1.43	2.18
1967 D	1.43	2.21
1968 D	1.43	2.21
1969 D	1.44	2.26
1970 U	1.44	2.27
1971 U	1.44	2.27
1972 U	1.44	2.27
1973 U	1.44	2.30
1974 U	1.44	2.30
1975 U	1.45	2.31

*Suspended sand plus wash load.
**Actual based on: A - Annual Flows, D - Daily Flows, U - USGS Estimates.

reduction in natural suspended sediment yield at the Santee station. The second major control within the San Diego River basin, San Vicente Reservoir, was completed and operational in 1943. For the period 1943 through 1975, there was a 90 percent reduction of the natural suspended sediment yield produced by San Vicente and El Capitan dams.

C9.9 Summary and Discussion

Particle-size analyses are available for all of the samples plotted in Fig. C9-6. However, the discharges are too low to make a determination as to the average amount of sand in suspension. For example, only four samples have discharges greater than 10 m^3/s, with the highest being 33.4 m^3/s. Therefore, again 25 percent and 10 percent have been used as the average ratios of suspended sand yield to total suspended sediment yield and bedload yield, respectively, in estimating average annual yields.

The sediment reductions caused by the dams as predicted herein can be compared with the amount of sediment stored behind the dams. Surveys are available for El Capitan and Cuyamaca reservoirs. From USGS Water Supply Papers 1121 and 2128, El Capitan lost 4.49 million m^3 of its capacity from 1894 to 1949. Using 1.04 tonnes/m^3 as a dry bulk density of the sediments gives an annual accumulation of 220,000 tonnes in El Capitan Reservoir and 1400 tonnes in Cuyamaca Reservoir for combined annual accumulation of 221,000 tonnes.

According to the technique presented in this report, the average total sediment yield of the San Diego River for 1935 to 1956 would have been 46,600 tonnes for natural conditions, and 12,000 tonnes for actual conditions. Unless there would have been extensive natural deposition within the basin, the estimate of natural sediment yield appears small in comparison with the reservoir storage. As an alternative, an upper-limit estimate of the natural annual sediment yield can be estimated as the combination of the annual actual sediment yield and the annual reservoir storage, totaling 233,000 tonnes. This estimate assumes that there would have been no natural storage below the dams, and that storage in San Vicente Reservoir from 1943 to 1956 would have been on the order of scour caused by large releases of clear water from El Capitan Reservoir in the 1938, 1939, and 1941 water years.

The two estimates of natural sediment yield differ by a factor of 5, for the period 1935 to 1956. The upper estimate is probably too high, because it neglects natural storage in the basin. On the other hand, the lower estimate is probably too low. It may be that the amount of sediment discharge data or the discharge range of the data is not sufficient to define the rating curve, Eq. C9-1. Or, it is possible that the basic assumptions of the technique outlined in Section C1.5 are too severely violated on the San Diego River. For example, it is possible that the dams have altered the natural rating curve.

Average annual sediment yield estimates are given in Table C9-5. For natural conditions, a range of values is given. In all cases, the lower limit is based on the standard technique and the upper limit is five times this value, based on the reservoir storage surveys. It is believed that the correct value is somewhere between these two.

The results indicate that the dams have severely reduced the actual yield of sand and gravel to almost nothing. The total actual yield of sand and gravel for the water years 1943 through 1975 is estimated at only 13,200 tonnes. By way of contrast, the Santa Clara River has delivered more than 72 times this amount of sand and gravel annually since 1928. In particular, on February 25, 1969, the Santa Clara River produced the same amount of sand and gravel, on the average, every 62 seconds for the full 24 hours, as the San Diego River produced in 33 years!

Table C9-5

San Diego River Average Annual Sediment Yield

Annual Sediment Yield in Tonnes

Mode of Transport and Sediment Size Class	Total Period of Record 1913 - 75		Period of Maximum Control 1943 - 75		Largest Event (1943 - 75) 1952 Water Year	
	Actual	Natural	Actual	Natural	Actual	Natural
Total Suspended Load	23,000	33,300-166,000	1,140	12,700-63,500	7,890	89,900-450,000
Suspended Fines (wash load)	17,300	25,000-	858	9,550-	5,910	67,400-337,000
Suspended Sand	7,750	8,330-41,600	286	3,180-15,900	1,970	22,500-112,000
Estimated Bedload (sand and gravel)	2,300	3,300-16,600	114	1,270-6,350	789	8,990-45,000
Total Sand and Gravel (bed-material load)	8,050	11,700-58,300	401	4,450-22,200	2,760	31,500-157,000
Total Sediment Load	25,300	36,700-184,000	1,260	14,000-69,900	8,670	98,900-494,000
$\frac{\text{Actual Sand Yield}}{\text{Natural Sand Yield}}$ (%)	69%		9%		9%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

C10 Tijuana River Basin

C10.1 Drainage Basin Description

The Tijuana River drainage basin is the most southerly of all the basins in the Sediment Management study area. It is the largest drainage basin of the eight perviously discussed. The basin has a drainage area of 4483 km^2, with 1196 km^2 in the United States and 3287 km^2 in Mexico (Fig. 10-1).*

The Tijuana River drainage basin is made up of two smaller basins: the Cottonwood Creek-Tecate Creek basin and the Rio de las Palmas basin. As can be seen from Table C10-1, where the two basins are compared, the Cottonwood Creek-Tecate Creek basin lies in a much cooler, wetter region than the Rio de las Palmas basin.

C10.2 Geological Setting

The central and eastern portion of the Tijuana River basin is located within the Peninsular Range batholith region. The intrusion of the batholith and the associated contact metamorphism of the surrounding Paleozoic rocks is considered to have occurred during the Mesozoic time (225 to 135 million years ago). The igneous rocks of the batholith exposed in the basin are composed primarily of grandiorite (quartz greater than 10 percent and palgioclase between 66 percent and 90 percent). Metamorphosed volcanics comprise almost the total area over which Rio de las Palmas drains. The coastal region of the Tijuana River basin is formed by gently seaward-dipping Tertiary and Quaternary marine and fluvial deposits of conglomerates, sandstones, and siltstones. These coastal sedimentary units are highly susceptible to landsliding along downcut stream channels in older marine terraces.

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*Data source: International Boundary and Water Commission (IBWC, 1973), figures do not necessarily agree with those given by the USGS.

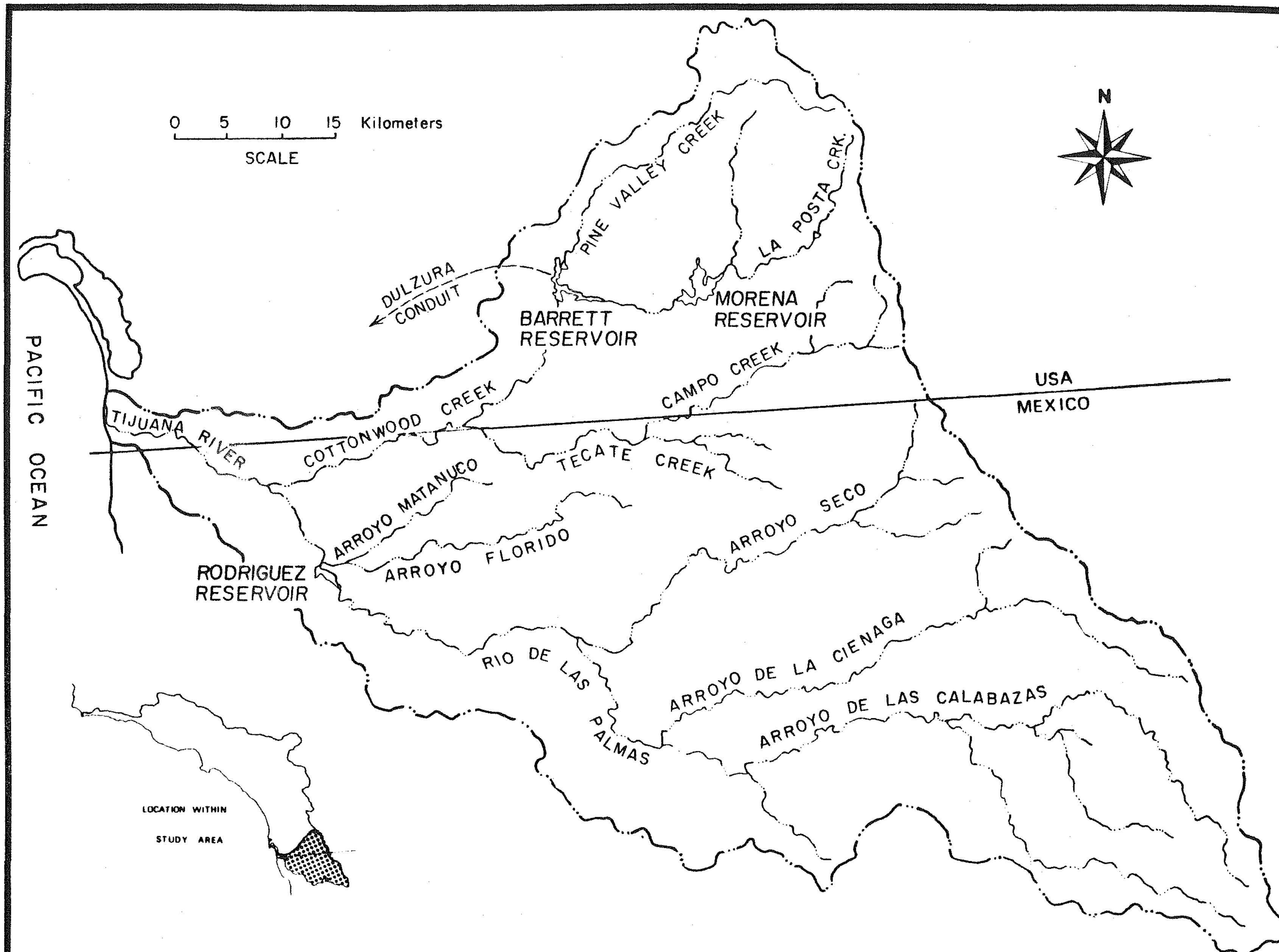


Figure C10-1 Tijuana River basin.

Table C10-1

Contrasting Cottonwood Creek-Tecate Creek and Rio de las Palmas Basins

		Cottonwood Creek-Tecate Creek Basin	Rio de las Palmas Basin
A.	Total Drainage Area	1245 km^2	2560 km^2
	1. Area within U.S.	1069 km^2	18 km^2
	2. Area within Mexico	176 km^2	2542 km^2
B.	Average Annual Temperature	15.5°C	29°C
C.	Range of Annual Rainfall	33-51 cm	12-37 cm
D.	Number of Gaging Stations within Basin	13	2
E.	Number of Major Reservoirs	2	1
	Total Capacity of Reservoirs within Basin	108.7 X $10^6 m^3$	136.9 X $10^6 m^3$
F.	Average Elevation of Headwater Region Above Sea Level	1790 m	1200 m

Data source: IBWC (1974).

Faulting is most predominant in the Tertiary basalt and sedimentary formations to the south of the Tijuana River mouth. These faults are NW-SE-trending dip-slip (relative vertical movement) and in some areas, produce horst graben structures, down-dropped blocks bounded on either side by faults.

The only faulting in the Cottonwood Creek-Tecate Creek basin is a NW-SE-trending fault that passes through the narrow Cottonwood Creek stream channel connecting Morena and Barrett reservoirs. Because of the linearity and the steep-walled canyon, this is most probably a fault-controlled stream channel.

C10.3 Control Facilities

There are three water-retention structures within the Tijuana River basin: Morena and Barrett reservoirs are owned by the City of San Diego and located on Cottonwood Creek, and the Rodriguez Reservoir is owned by the Mexican government and located on Rio de las Palmas (Fig. C10-1). The capacity, completion date, and drainage area for each reservoir are listed in Table C10-2.

Rodriguez Reservoir

Rodriguez Dam is located in Mexico on Rio de las Plamas, 8.9 km upstream of the confluence with Cottonwood Creek. Storage began in Rodriguez Reservoir on September 22, 1936. Water is diverted directly into the aqueduct for domestic use in Tijuana and into the north and south canals for irrigation of farmlands in Mexico. Records of inflows and spills are published by the International Boundary and Water Commission (IBWC) in the Western Water Bulletin series.

Morena and Barrett Reservoirs

Morena Dam is located on Cottonwood Creek, 13.7 km upstream from Battett Dam, which in turn is located 10.5 km upstream from the confluence with Rio de las Palmas. Storage began in March 1910 in Morena Reservoir, and in January 1921 in Barrett Reservoir.

Table C10-2

Control Structures of the Tijuana River Basin

Reservoir	Capacity (106 m^3)	Completion date	Controlled Drainage Area (km^2)
Morena	61.9	March 1910	295
Barrett	55.2	January 1921	645*
Rodriguez	137	September 1936	2530

Conduit	Completion date	Diversion From/To
Dulzura	1909	Conduit carries diversions from Barrett Reservoir across the drainage divide into Otay Reservoir for municipal use by the City of San Diego. Prior to completion of Barrett Reservoir water was diverted directly from Cottonwood Creek below Morena Reservoir.
Rodriguez Aqueduct and canal system	1937	Water is diverted from Rodriguez Reservoir for municipal use by City of Tijuana, and to north and south canals for irrigation. The north canal delivers water to Tijuana Valley north of the Rio de las Palmas and the south canal delivers water to areas in the valley south of the Rio de las Palmas and the Tijuana River.
Otay Aqueduct	1972	Colorado River water is diverted to Rodriguez Reservoir for emergency use by the City of Tijuana.

*Includes drainage area controlled by Morena Dam.

NOTE: Total Drainage area of basin is 4483 km^2.

Water from Morena Reservoir is released down Cottonwood Creek to Barrett Reservoir. Water from Barrett Reservoir (including Morena water) is transported through the Dulzura Conduit out of the drainage basin to the Otay Reservoir for municipal use by the City of San Diego. Records of inflows and spills for these reservoirs have been published for some years by the USGS and the IBWC. However, since neither record is complete and there are slight differences between the data sets, a complete record was obtained from the City of San Diego.

C10.4 Gaging Stations

Gaging station locations within the basin are shown in Fig. C10-2 and listed in Table C10-3. Of the eighteen stations listed, fourteen have record lengths of 15 years or more, and only two are maximum discharge, crest-stage stations. Sixteen of the eighteen stations are located at the international border, or within the USA, an area that represents only 27 percent of the basin area.

C10.5 Stream Bed Characteristics

The bed elevation of the Tijuana River is plotted against distance from the coast in Fig. C10-3. The Tijuana River has the gentlest sloping channel among the eight drainages with moderate development, with an average slope in the lower 80 km of 3.90 m/km.

The sediment station (11013500) is located 4.7 km upstream from the mouth of the Tijuana River (Fig. C10-3). The slope along this lower 20 km reach is 2.38 m/km. The surface bed material at this station, based on five composite samples collected by the USGS between June 1969 and August 1973 and one sample collected by Brownlie on November 24, 1978, has an average median diameter of 0.37 mm and an average geometric standard deviation of 2.1. The particle-size distributions of these samples are shown in Fig. C10-4.

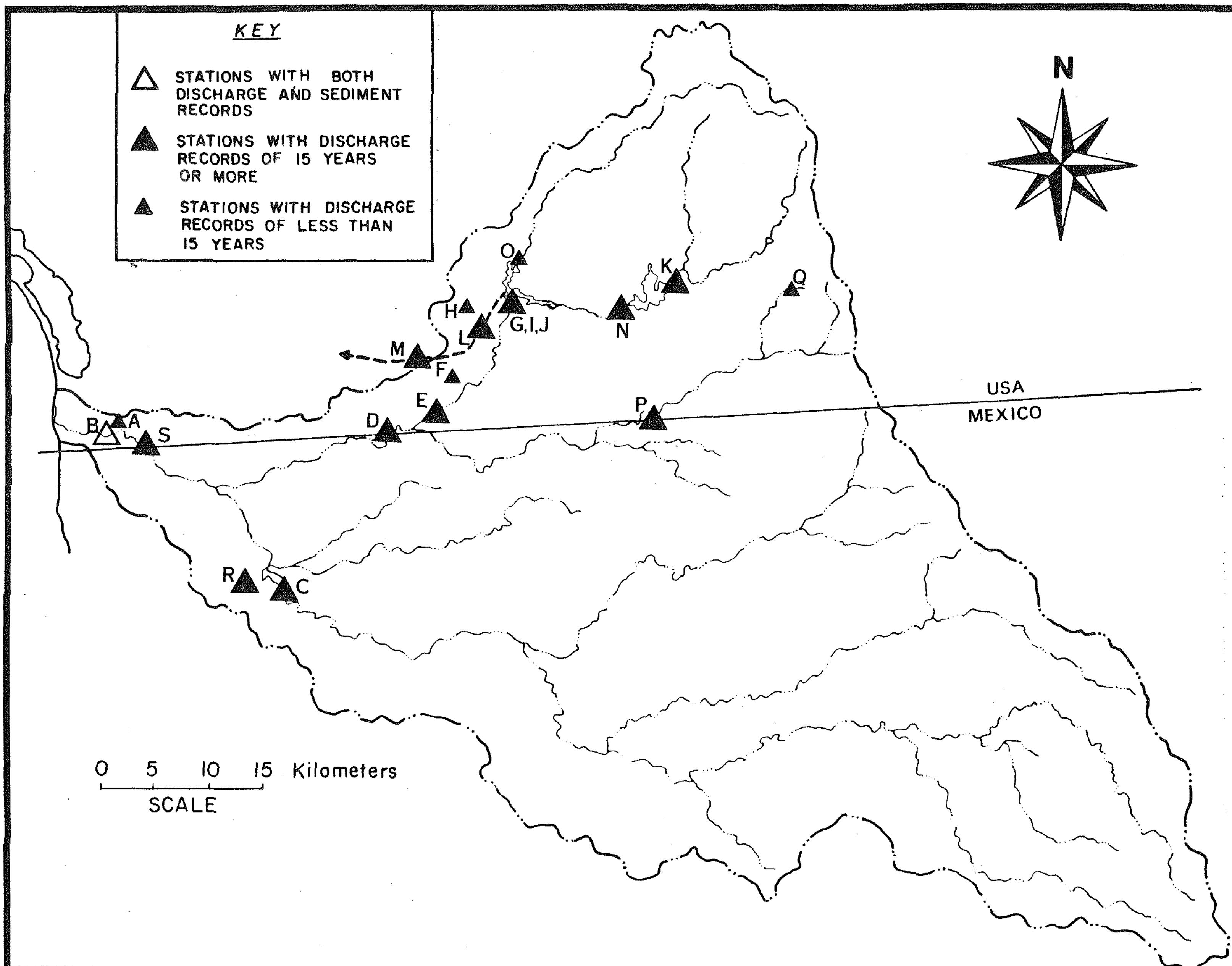


Figure C10-2 Location of streamflow and sediment gaging stations within the Tijuana River basin.

Table C10-3

Gaging Stations within the Tijuana River Basin

MAP CODE	CLASS	DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
A	3X	X8-1090		TIAJUANA R TRIB A SAN YSIDRO	32-33-30	117-03-36	SDG	1401	SD	1964			P	5.96		L
B*	1	X8-1100	11-0135.00	TIJUANA R NR NESTOR	32-33-00	117-05-00	SDG	5000	SD	1914		21	F	4377.		F
C*	7	X8-1300	11-0132.00	RODRIGUEZ RES A RODR DM NR DULZUR	32-26-06	116-54-24	MEX	5694	SD	1937			G	2530.		F
D*	1	X8-1600	11-0130.00	TIJUANA R NR DULZURA	32-33-54	116-46-24	SDG	5000	SD	1936			G	1246.		F
E*	1	X8-2100	11-0120.00	COTTONWOOD C AB TECATE C NR DULZ	32-34-30	116-45-12	SDG	5000	SD	1936			G	803.		F
F*	3X	X8-2130	11-0119.00	POTRERO C TRIB NR BARRET	32-36-06	116-41-06	SDG	5000	SD	1961			G	2.02		F
G*	1	X8-2195	11-0111.00	COTTONWOOD C BL BARR DM NR DULZUR	32-39-12	116-40-42	SDG	5229	SD	1952			G	642.		L
H	1	X8-2200	11-0109.00	WILSON C TRIB NR DULZURA	32-43-24	116-42-06	SDG	5000	SD	1961	1973		G	1.58		F
I*	6	X8-2210	11-0110.00	COTTONWOOD C A BARR DM NR DULZURA	32-40-42	116-40-12	SDG	5229	SD	1906		23	G	635.		F
J	1	X8-2300	11-0110.00	COTTONWOOD C A BARRETT DAM	32-40-42	116-40-18	SDG	5000	SD	1906	1915		E	635.		SF
K*	6	X8-2430	11-0100.00	COTTONWOOD C A MORENA DAM	32-41-00	131-63-12	057	4412	SJ	1916	1968		F	295.		F
L*	1	X8-2925	11-0115.00	DULZURA COND NR DULZURA	32-37-12	116-45-54	SDG	5000	SD	1909	1958	23	G			F
M*	1	X8-2960	11-0114.90	DULZURA COND BL BARRET DM	32-40-42	116-40-12	SDG	5000	SD	1953			G			N
N*	1	X8-2980	11-0100.50	MORENA DAM OL WEIR A MORENA DAM	32-41-06	116-32-48	SDG	5229	SD	1911			G	311.		L
O	5	X8-3200	11-0105.00	PINE VALLEY C NR JAMUL	32-40-42	116-40-18	SDG	5000	SD	1906	1908		G	252.		F
P*	1	X8-4200	11-0125.00	CAMPO C NR CAMPO	32-35-24	116-31-30	SDG	5000	SD	1936			G	220.		F
Q	1	X8-4500	11-0121.00	MILLER C NR LIVE OAK SPRINGS	32-42-12	116-21-48	SDG	5000	SD	1961	1964		G	2.59		F
R*	1			TIJUANA R A INT BOUNDARY	32-33-00	117-02-00		IBWC		1947				4370.		
S*	1			DIV F RODRIGUEZ RES,BAJA CA	32-26-10	116-54-40		IBWC		1936						

* Stations with record lengths of 15 years or more.
See Section C17 for a complete explanation of codes and abbreviations.

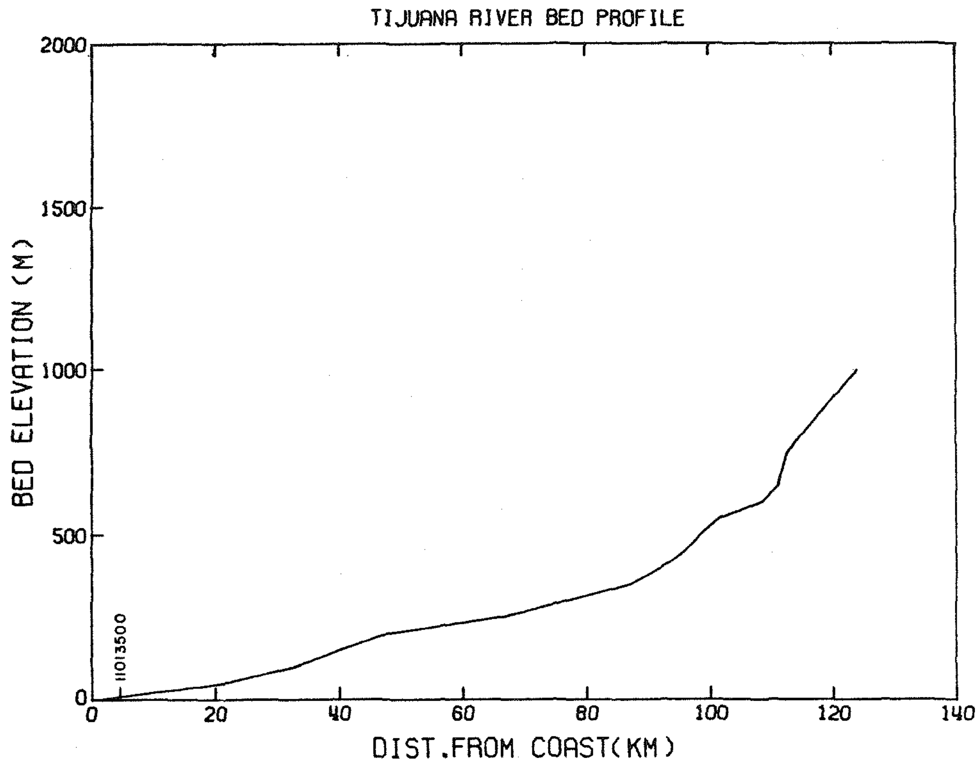


Figure C10-3 Bed profile for main channel of the Tijuana River.

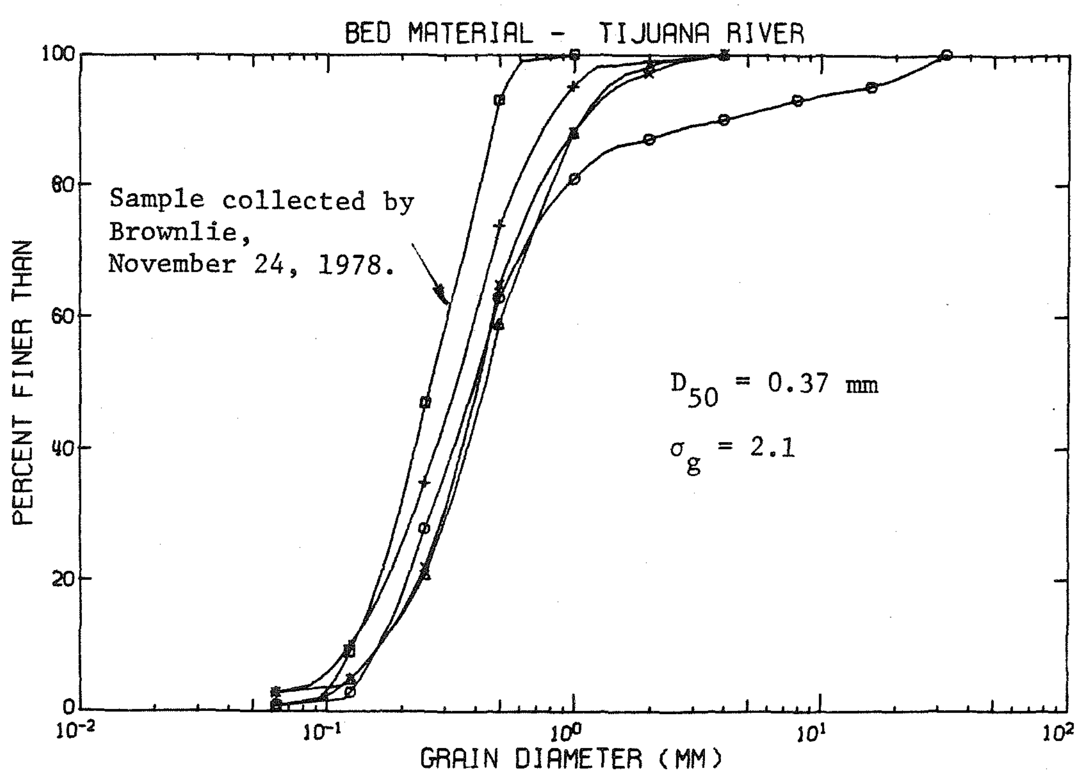


Figure C10-4 Composite bed-material samples collected at station 11013500 by the USGS between June 13, 1969 and August 16, 1973 and by Brownlie on November 24, 1978.

A sketch of the lower reach of the river (Fig. C10-5) reveals that there is little development in this part of the basin. The river channel downstream of the sediment station is, for the most part, allowed to follow its natural course. Because the drainage area of the station (11013500) represents over 99 percent of the total drainage area of the basin, sediment discharge gaged at this station gives a good representation of sediment discharge to the coastal marsh area.

C10.6 Sediment Rating Curve

Actual sediment deliveries for the calendar years 1937 to 1969 were estimated with the use of sediment rating curves. The instantaneous rating curve was constructed from 16 published and 27 unpublished USGS suspended sediment concentration measurements, collected between February 12, 1973 and March 3, 1976. This resulting curve, shown in Fig. C10-6, was fitted by the technique described in Section C18.1. The equation for the rating curve is

$$\hat{Q}_{ss} = 255\ Q^{1.22} \tag{C10-1}$$

where $\hat{Q}_{ss}$ is the predicted suspended sediment transport rate in tonnes/day and Q is the water discharge in m^3/s. The correlation coefficient between the logarithms of Q_s and Q is 0.951.

To determine the sediment yield that would have occurred under natural uncontrolled conditions, a relationship (Fig. C10-7) between annual suspended sediment yield and annual storm flow was needed. From inspection of streamflow records, it was decided that there are no significant base flows at the 11013500 station. Therefore, total annual flows are assumed to be entirely storm flows. (A typical annual streamflow sequence is shown in Fig. C10-8.) The relationship, or annual sediment rating curve, is found to be

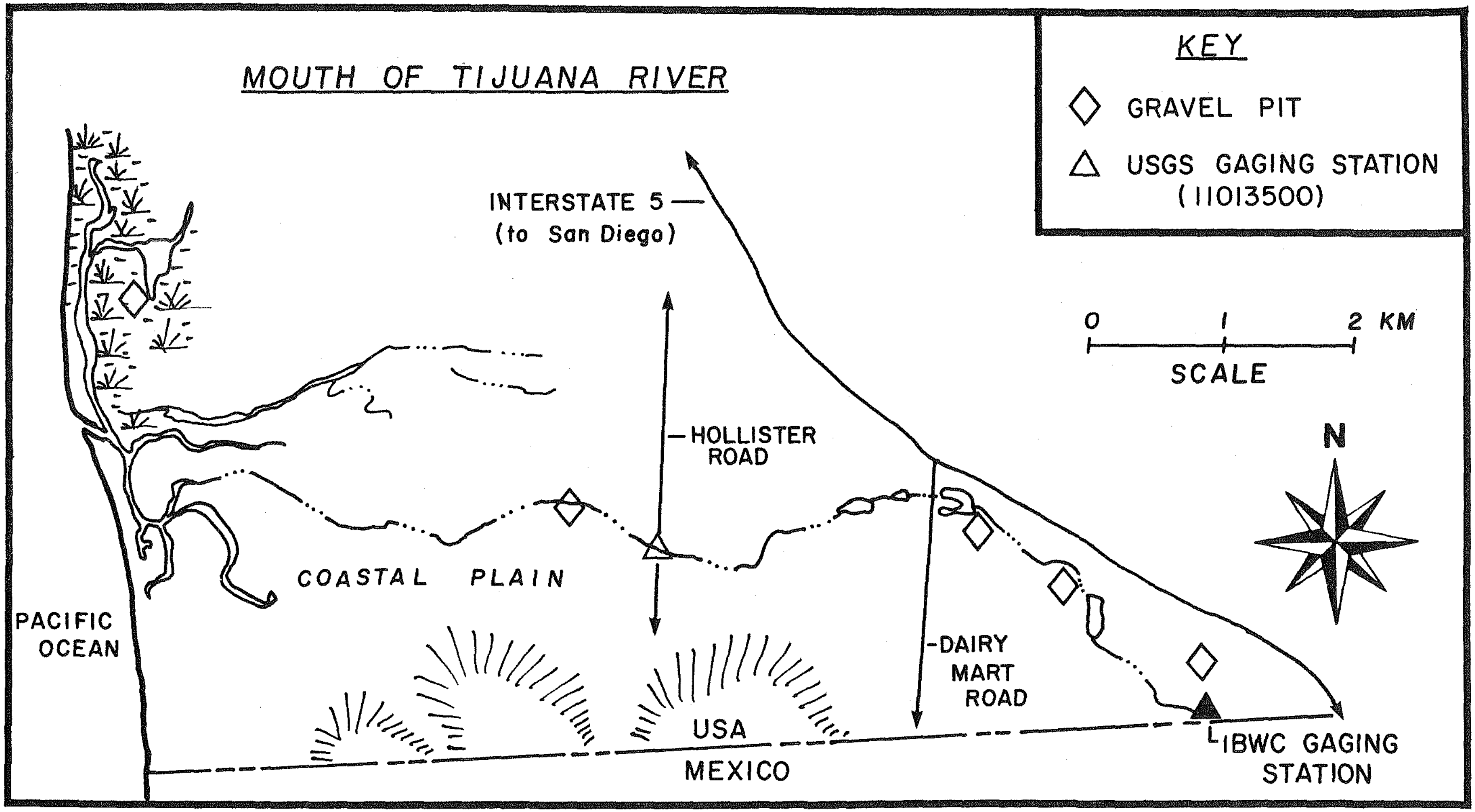


Figure C10-5 Lower reach of the Tijuana River.

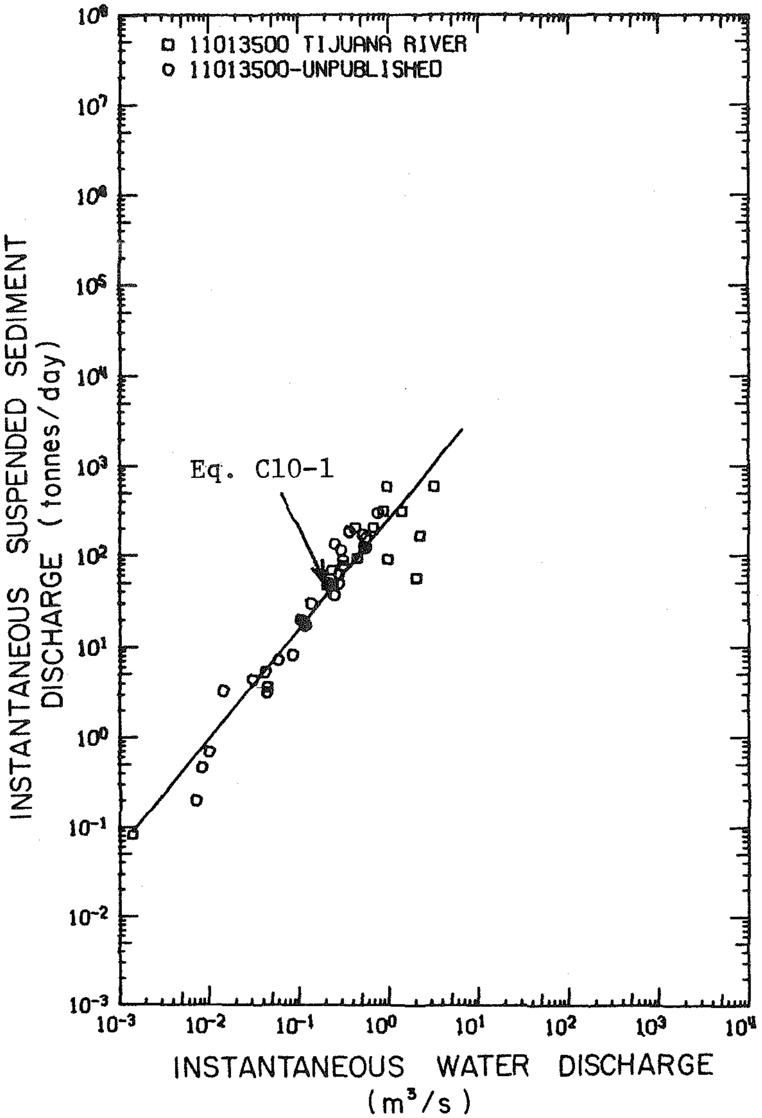


Figure C10-6 Relation of instantaneous sediment discharge to water discharge at Tijuana River station 11013500, 1973-76

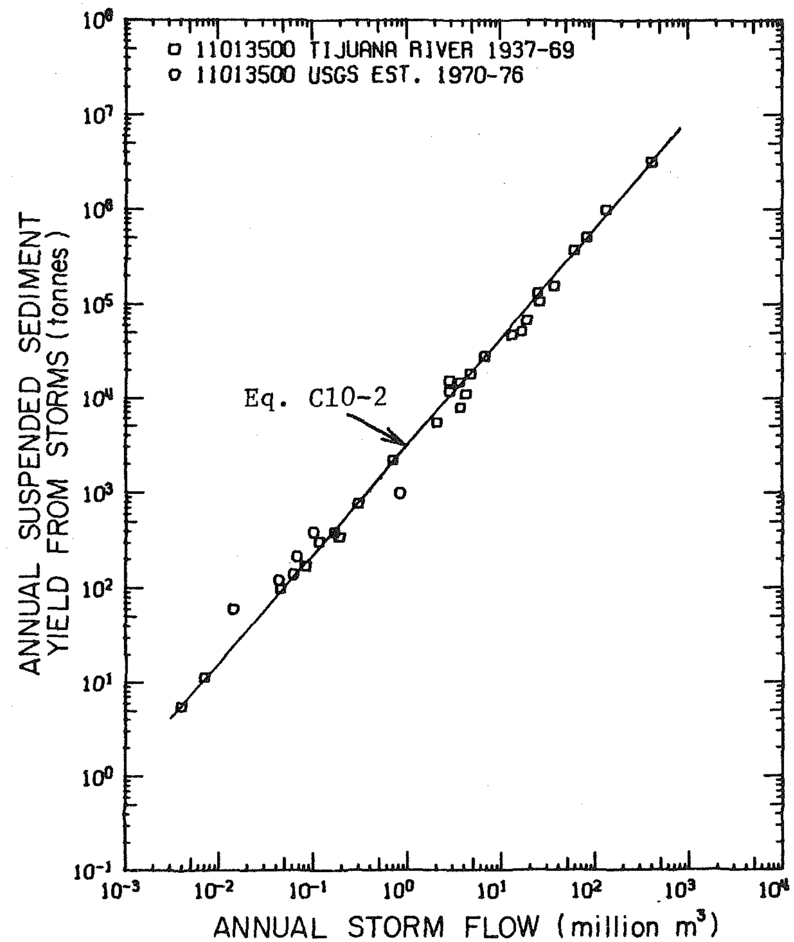


Figure C10-7 Relation of annual suspended sediment delivered by storms to annual storm flows at Tijuana River station 11013500 1937 to 1976.

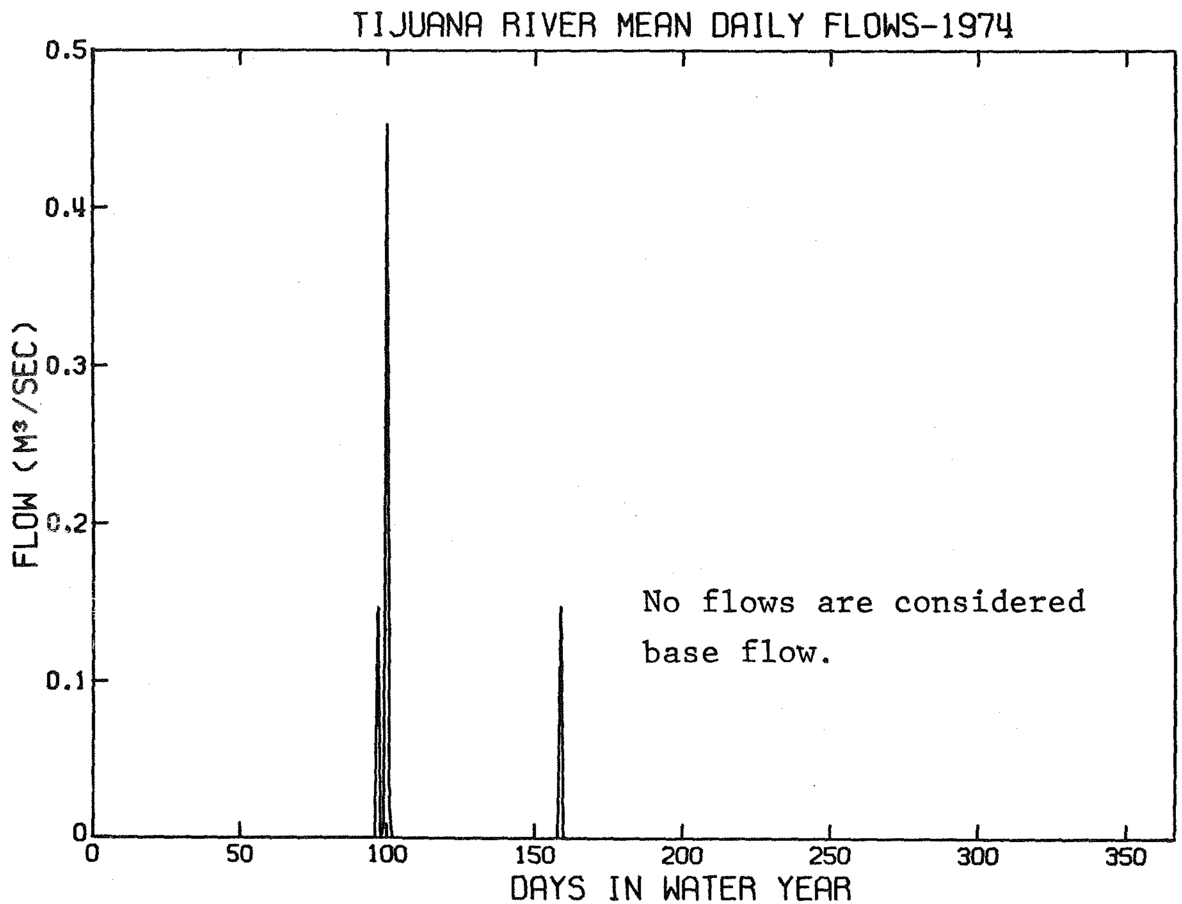


Figure C10-8 Typical annual sequence of mean daily flows (1974 water year).

$$\hat{\mathcal{V}}_{ss} = 3160\ \mathcal{V}^{1.15} \qquad \text{(C10-2)}$$

where $\hat{\mathcal{V}}_{ss}$ is the predicted annual suspended sediment yield in tonnes, and $\mathcal{V}$ is the annual runoff, in million m^3. Equation C10-2, illustrated in Fig. C10-7, was determined by the method described in Section C18.2.

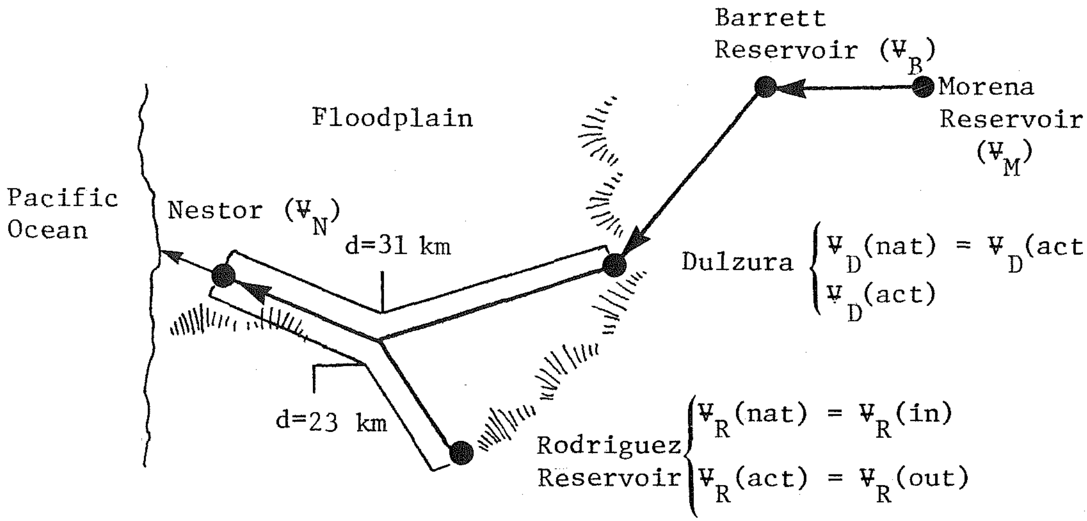
C10.7 Estimation of Natural Flows

The calculation of natural flows at Nestor was complicated in that the effects of three reservoirs had to be considered. The procedure used is diagrammed schematically in Fig. C10-9. The natural flows at Nestor were determined by combining natural flows at the Dulzura station (11013000) and at Rodriguez Dam, corrected for percolation losses, with local runoff. Natural flows at Dulzura were taken as the sum of the actual flows at Dulzura plus the inflows to Barrett and Morena reservoirs, minus spills from Barrett Reservoir. Natural flows at Rodriquez Dam were taken as the inflows to the reservoir. Local runoff was taken as the actual flow at Nestor, minus actual flows at Dulzura and Rodriguez Dam, corrected for percolation.

Percolation losses for flows across the floodplain (i.e. downstream of Rodriguez Dam and Dulzura), were based on a correlation between annual flows at Nestor, $\mathcal{V}_N$, and at the international border, $\mathcal{V}_I$. The correlation (Fig. C10-10) can be represented (see Section C18.3) by

$$\hat{\mathcal{V}}_N = 0.34\ \mathcal{V}_I^{1.34} - 0.106 \qquad \text{(C10-3)}$$

where $\hat{\mathcal{V}}_N$ is the predicted value of the flow at Nestor, and the units are million m^3. The equation is applicable for $0.25 \leq \mathcal{V}_I \leq 23.75$. Below this range, percolation losses are taken to be 100 percent and above it, percolation losses are neglected. Because the



Dulzura $\begin{cases} \forall_D(\text{nat}) = \forall_D(\text{act}) + \forall_B(\text{out}) - \forall_B(\text{in}) + \forall_M(\text{in}) \\ \forall_D(\text{act}) \end{cases}$

Rodriguez Reservoir $\begin{cases} \forall_R(\text{nat}) = \forall_R(\text{in}) \\ \forall_R(\text{act}) = \forall_R(\text{out}) \end{cases}$

$$\forall_N(\text{nat}) = [\forall_D(\text{nat}) - P_{31}(\text{nat})] + [\forall_R(\text{nat}) - P_{23}(\text{nat})] + \forall_{\text{local}}(\text{act})$$

where: $\forall_{\text{local}}(\text{act}) = \forall_N(\text{act}) - [\forall_D(\text{act}) - P_{31}(\text{act})] - [\forall_R(\text{act}) - P_{23}(\text{act})]$

$$P_d(\text{nat}) = P[d,\forall(\text{nat})],\ P_d(\text{act}) = P[d,\forall(\text{act})]$$

and $P[d,\forall] = \frac{d}{5}(\forall - 0.34\ \forall^{1.34} + 0.106)$

C200

NOTE: $\forall$ = annual runoff (10^6 m^3), P = annual percolation loss (10^6 m^3), d = distance (km).

Figure C10-9 Calculation of natural flows at Nestor.

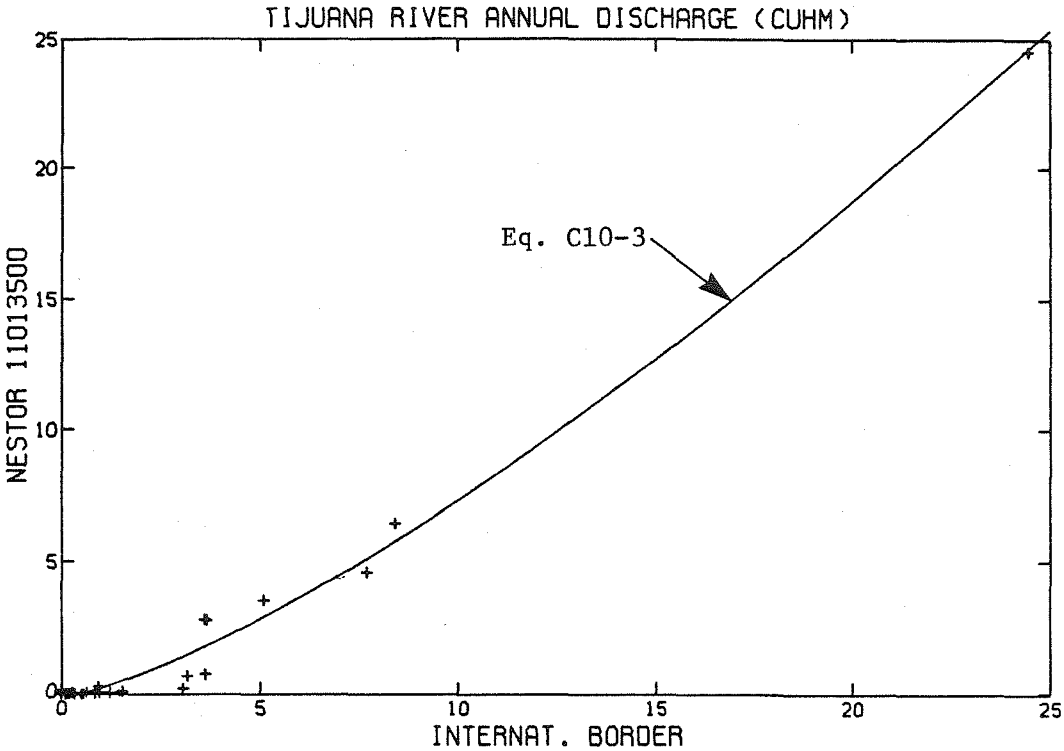


Figure C10-10 Correlation between annual flows at Nestor station, 11013500, and international border station, which was used in calculating percolation losses.

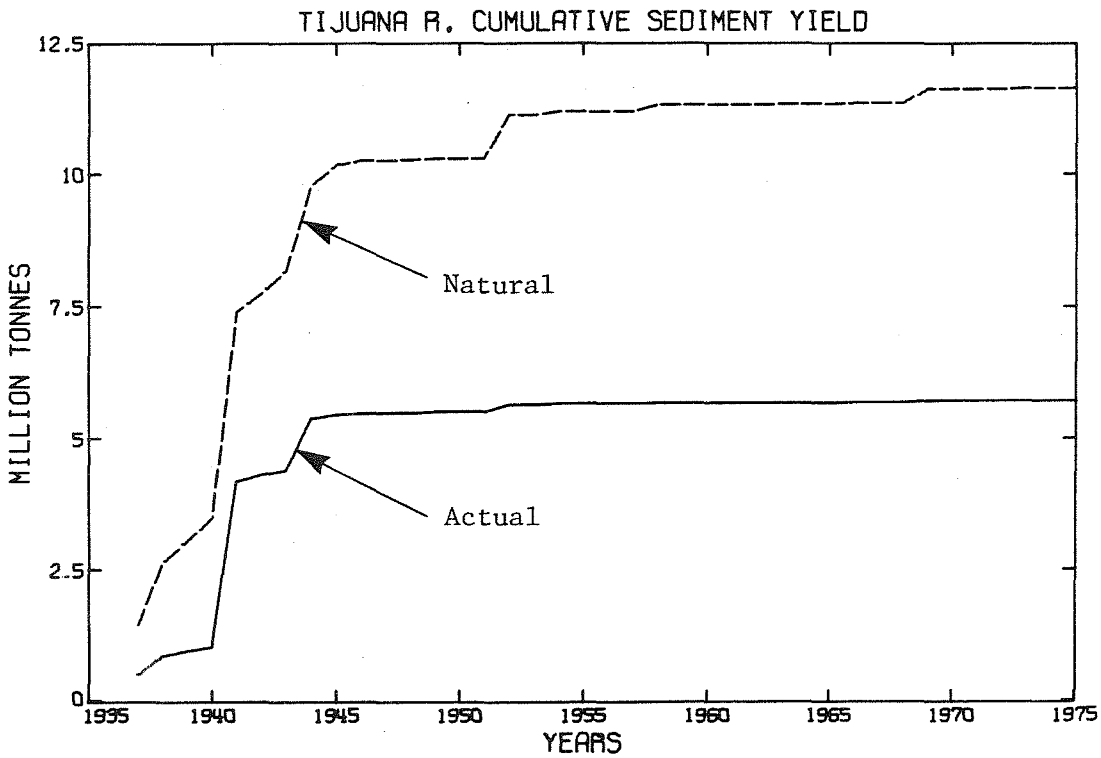


Figure C10-11 Cumulative natural and actual suspended sediment yield at Tijuana River station 11013500.

stations are 5 km apart, the percolation loss, P, of a flow, ¥, flowing over distance d can be obtained by rearranging Eq. C10-3

$$P_d = \frac{d}{5}(¥-0.34\ ¥^{1.34}-0.106 \qquad \text{(C10-4)}$$

Percolation losses upstream from Dulzura were neglected for several reasons: (1) The data base is not sufficient to make percolation calculations, (2) Percolation losses in the narrow valleys were believed to be small, and (3) Any artificial diversions between the two stations used for derivation of Eq. C10-3 would tend to exaggerate the percolation losses given by Eq. C10-4 for the downstream reaches. This effect would tend to counteract the neglect of percolation in the upstream reaches.

C10.8 Suspended Sediment Yield

Having predicted annual natural runoff at Nestor, the natural annual suspended sediment yields were calculated from Eq. C10-2. The detailed results are given in Table C10-4 and cumulative results are given in Table C10-5 and Fig. C10-11.

All the control structures within the Tijuana River drainage basin were already in operation by 1937, the earliest date of our predictions, thus it is hard to evaluate the absolute effect of their presence. However, for the period from 1937 to 1975 the calculated average annual suspended sediment delivery under natural and actual conditions is 0.26 million tonnes and 0.13 million tonnes, respectively, representing a 50 percent reduction of natural suspended sediment delivery to the coast.

Table C10-4
Tijuana River
Actual (ACT) vs. Natural (NAT)

	ANNUAL WATER FLOW (10^6 m3)					ANNUAL SUSPENDED SEDIMENT YIELD (TONNES)				
	1	2	3	1+2	1+3	4	5	6	4+5	4+6
CALENDAR YEAR*	BASE FLOW	STORM ACT FLOW	STORM NAT FLOW	TOTAL ACT FLOW	TOTAL NAT FLOW	BASEFLOW SEDIMENT	STORM ACT SED	STORM NAT SED	TOTAL ACT SED	TOTAL NAT SED
1937 D	0.0	82.06	201.28	82.06	201.28	0.0	515027.06	1445829.00	515027.06	1445829.00
1938 D	0.0	61.27	170.25	61.27	170.25	0.0	377608.94	1223562.00	377608.94	1223562.00
1939 D	0.0	24.15	81.28	24.15	81.28	0.0	99651.00	402567.88	99651.00	402567.88
1940 D	0.0	13.58	66.29	13.58	66.29	0.0	70753.88	438421.56	70753.88	438421.56
1941 D	0.0	410.49	495.86	410.49	495.86	0.0	3144829.00	3908314.00	3144829.00	3908314.00
1942 D	0.0	30.86	69.56	30.86	69.56	0.0	136253.44	347001.88	136253.44	347001.88
1943 D	0.0	21.29	92.79	21.29	92.79	0.0	79371.69	431569.88	79371.69	431569.88
1944 D	0.0	131.30	200.17	131.30	200.17	0.0	985064.25	1600067.00	985064.25	1600067.00
1945 D	0.0	18.75	81.03	18.75	81.03	0.0	70778.56	381124.13	70778.56	381124.13
1946 D	0.0	8.77	31.51	8.77	31.51	0.0	23616.94	102865.00	23616.94	102865.00
1947 D	0.0	2.81	2.81	2.81	2.81	0.0	7133.72	7133.72	7133.72	7133.72
1948 D	0.0	0.72	0.72	0.72	0.72	0.0	1435.00	1435.00	1435.00	1435.00
1949 D	0.0	6.51	6.51	6.51	6.51	0.0	28178.07	28178.07	28178.07	28178.07
1950 D	0.0	0.19	0.19	0.19	0.19	0.0	344.00	344.00	344.00	344.00
1951 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952 D	0.0	24.53	119.81	24.53	119.81	0.0	131539.50	815503.19	131539.50	815503.19
1953 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954 D	0.0	3.55	14.76	3.55	14.76	0.0	14712.49	75668.63	14712.49	75668.63
1955 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957 D	0.0	0.04	0.04	0.04	0.04	0.0	98.38	98.38	98.38	98.38
1958 D	0.0	2.82	23.00	2.82	23.00	0.0	11827.30	132050.94	11827.30	132050.94
1959 D	0.0	0.11	0.11	0.11	0.11	0.0	307.19	307.19	307.19	307.19
1960 D	0.0	0.16	0.16	0.16	0.16	0.0	385.92	385.92	385.92	385.92
1961 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962 D	0.0	0.08	0.08	0.08	0.08	0.0	171.58	171.58	171.58	171.58
1963 D	0.0	0.01	0.01	0.01	0.01	0.0	11.20	11.20	11.20	11.20
1964 N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965 D	0.0	0.68	0.68	0.68	0.68	0.0	2135.84	2135.84	2135.84	2135.84
1966 D	0.0	2.79	4.35	2.79	4.35	0.0	15423.98	25709.34	15423.98	25709.34
1967 D	0.0	0.26	0.26	0.26	0.26	0.0	678.92	678.92	678.92	678.92
1968 D	0.0	0.05	0.05	0.05	0.05	0.0	114.67	114.67	114.67	114.67
1969 D	0.0	4.63	46.46	4.63	46.46	0.0	18152.27	257599.88	18152.27	257599.88
1970 U	0.0	0.06	0.06	0.06	0.06	0.0	179.62	179.62	179.62	179.62
1971 U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972 N	0.0	0.02	0.02	0.02	0.02	0.0	50.26	50.26	50.26	50.26
1973 U	0.0	0.08	4.12	0.08	4.12	0.0	337.71	30582.20	337.71	30582.20
1974 U	0.0	0.07	0.07	0.07	0.07	0.0	212.12	212.12	212.12	212.12
1975 U	0.0	0.06	0.06	0.06	0.06	0.0	137.98	137.98	137.98	137.98
1976 U	0.0	0.82	-1.00	0.82	-1.00	0.0	983.50	-1.00	983.50	-1.00

NOTES: Sediment yield refers to suspended sediment.
Negative one (-1.00) indicates data unavailable.

Table C10-5
Tijuana River (11012500)
Cumulative Suspended* Sediment Yields (10^6 Tonnes)

Water Year**	Actual	Natural
1937 D	0.52	1.45
1938 D	0.89	2.67
1939 D	0.99	3.07
1940 D	1.06	3.51
1941 D	4.21	7.42
1942 D	4.34	7.77
1943 D	4.42	8.20
1944 D	5.41	9.80
1945 D	5.48	10.18
1946 D	5.50	10.28
1947 D	5.51	10.29
1948 D	5.51	10.29
1949 D	5.54	10.32
1950 D	5.54	10.32
1951 N	5.54	10.32
1952 D	5.67	11.13
1953 N	5.67	11.13
1954 D	5.69	11.21
1955 N	5.69	11.21
1956 N	5.69	11.21
1957 D	5.69	11.21
1958 D	5.70	11.34
1959 D	5.70	11.34
1960 D	5.70	11.34
1961 N	5.70	11.34
1962 D	5.70	11.34
1963 D	5.70	11.34
1964 N	5.70	11.34
1965 D	5.70	11.34
1966 D	5.72	11.37
1967 D	5.72	11.37
1968 D	5.72	11.37
1969 D	5.74	11.63
1970 U	5.74	11.63
1971 U	5.74	11.63
1972 N	5.74	11.63
1973 U	5.74	11.66
1974 U	5.74	11.66
1975 U	5.74	11.66

*Suspended sand plus washload.
**Actual based on: D-Daily Flows, N-No Flows
U-USGS Estimates

C10.9 Summary and Discussion

Average annual sediment yields are compiled in Table C10-6. Again, in the absence of sufficient data, 25 percent and 10 percent have been taken as the average ratios of suspended sand yield and bedload yield, respectively, to suspended sediment yield. The results indicate that for the water years 1937 through 1975, slightly more than 2 million tonnes of sand and gravel have been prevented from reaching the coast by the works of man.

Surveys of Barrett and Morena reservoirs provide a useful, though not complete, comparison between the predicted reduction of sediment yield, and the storage of sediment within the basin, behind dams. Surveys of Morena Reservoir (City of San Diego, et al., 1953) revealed an average annual accumulation of 173,000 m^3 (140.2 acre-feet) for 1935 to 1948. The measured average density of the sediment was 1.11 tonnes/m^3 (69.6 lb/ft^3), giving an average annual accumulation by mass of 192,000 tonnes. Capacities for Barrett Reservoir given by the IBWC (1975) and the USGS (Water Supply Paper 1121) indicate an annual accumulation of 175,000 m^3 (142.5 acre-feet) for 1921 to 1955. Assuming an average sediment density of 1.04 tonnes/m^3 (65 lb/ft^3), and, based on Morena surveys, assuming that the average accumulation rate for 1935 to 1948 would be about 75 percent that for the whole period, 1921 to 1955, gives an average annual accumulation by mass of 137,000 tonnes for 1935 to 1948. Therefore, the combined annual accumulation for Barrett and Morena reservoirs is estimated at 329,000 tonnes, for 1935 to 1948.

From Table 10-5, the total reduction of natural suspended sediment yield for the water years 1937 through 1948 is seen to be 4.78 million tonnes. Dividing this figure by 12, the number of years, and scaling by 1.1 to include bedload gives an annual reduction of 438,000 tonnes, compared to 329,000 tonnes/year stored

Table C10-6

Tijuana River Average Annual Sediment Yield

Annual Sediment Yield in Tonnes

Mode of Transport and Sediment Size Class	Total Period of Record 1937 - 75		Largest Event 1941 Water Year	
	Actual	Natural	Actual	Natural
Total Suspended Load	147,000	299,000	3,140,000	3,910,000
Suspended Fines (wash load)	110,000	224,000	2,360,000	2,930,000
Suspended Sand	36,800	74,700	786,000	977,000
Estimated Bedload (sand and gravel)	14,700	29,900	314,000	391,000
Total Sand and Gravel (bed-material load)	51,500	105,000	2,360,000	2,930,000
Total Sediment Load	162,000	329,000	3,460,000	4,300,000
$\frac{\text{Actual Sand Yield}}{\text{Natural Sand Yield}}$ (%)	49%		80%	

NOTES: Total Suspended Load + Bedload = Total Sediment Load.
Suspended Sand + Bedload = Bed-material Load.
See Section C1.5 for a complete definition of terms.

in Barrett and Morena reservoirs. Consequently, Barrett and Morena reservoirs account for 75 percent of the predicted reduction of natural sediment yield for the water years 1937 through 1948. The remainder of the reduction could possibly be explained by a balance between storage in Rodriguez Reservoir and channel storage, and channel erosion.

The City of San Diego, et al. (1953) also reported mechanical analyses of reservoir sediment samples. The sediment samples contained 71.7 percent sand and gravel by weighted average. However, the weighted average includes samples in regions of scour on the Morena and Cottonwood creek arms of the reservoir. Such samples, which are in effect channel samples, tend to exaggerate the fraction of sand and gravel in the sediment. For example, the lower reservoir samples contained only 20.2 percent fine sand and 79.8 percent silt and clay. On the basis of these results, it does not seem unreasonable to assume that the average total sediment yield at the coast was 31.8 percent sand and gravel, as was assumed for the average values given in Table C10-6.

C11 Moderately Developed Basins - Summary and Conclusions

In sections C3 through C10 of this report, estimates of the natural and actual historical sediment yields of the eight moderately developed river basins of southern California were developed. In this section, the findings are summarized and compared. In this way, the relative importance of each basin as a producer of littoral material can be assessed. This section also contains a discussion of the accuracy of the sediment yield predictions.

C11.1 Comparison of Basins

The most significant data used in predicting the sediment yields for six of the eight basins were probably the instantaneous suspended sediment concentration measurements made by the USGS. From these measurements, instantaneous rating curves were developed to predict suspended sediment discharge (see Table C11-1). By using these rating curves with daily flow data, daily and then annual estimates of suspended sediment yield were determined. By substituting USGS estimates where available, and correcting for base flows, annual rating curves were developed for predicting suspended sediment yield (see Table C11-2).

The data base for the instantaneous rating curves for the Ventura, Santa Clara, Santa Margarita, and San Luis Rey rivers includes measurements made during the storms of 1969, at high discharges. On the other hand, the rating curves for the San Diego and Tijuana rivers were developed solely from low discharge samples collected after 1969. Therefore, it is not clear how well these curves will predict sediment discharges at higher water discharges. From Table C11-1, it can be seen that the exponents for these two rivers are somewhat lower than those of the four northern rivers. Perhaps, this is due to the problem just stated, or perhaps it is due to some physiographic differences.

Table C11-1

Instantaneous Sediment Rating Curves

USGS Station	River	No. of Samples	Highest Discharge (m^3/s)	Correlation Coeff. of Logarithms	Coefficient,* a	Exponent,* b
11118500	Ventura	49	555	0.978	14.2	1.83
11114000	Santa Clara	46	4,620	0.942	24.4	1.73
11046000	Santa Margarita	25	527	0.951	8.90	1.66
11042000	San Luis Rey	18	81.8	0.985	26.0	1.78
11022500	San Diego	27	33.4	0.970	8.73	1.58
11013500	Tijuana	43	3.23	0.951	255	1.22

*Rating curve is of the form $\hat{Q}_{ss} = aQ^b$ where $\hat{Q}_{ss}$ is the predicted instantaneous suspended sediment discharge, in tonnes/day, and Q is the instantaneous water discharge, in m^3/s.

Table C11-2

Annual Storm Sediment Rating Curves

USGS Station	River	Number of Samples			Correlation Coeff. of Logarithms	Coefficient** A	Exponent** B
		Predicted*	USGS Est.	Total			
11118500	Ventura	35	7	42	0.978	588	1.52
11114000	Santa Clara	16	10	26	0.990	938	1.53
11046000	Santa Margarita	29	--	29	0.976	132	1.58
11042000	San Luis Rey	23	--	23	0.971	544	1.54
11022500	San Diego	47	7	54	0.988	139	1.43
11013500	Tijuana	27	6	33	0.996	3120	1.15

* Predictions based on daily streamflow data and instantaneous rating curves.

**Rating curve has the form $\hat{V}_{ss}(\text{storm}) = A[V(\text{storm})]^B$, where $\hat{V}_{ss}$(storm is the predicted annual suspended sediment yield delivered by storms, in tonnes, and V (storm) is the annual storm flow, in million m^3.

NOTE: Rating curves for Calleguas Creek and the San Dieguito River were not developed in the same manner as those given above (See Sections C5.6 and C8.6.).

For example, for the discharges sampled, the Tijuana River had high silt concentrations which were not strongly related to discharge. Therefore, the coefficient in the instantaneous rating curve is high, and the exponent is close to one.

Actual and natural average annual sand and gravel yields for the period 1951 through 1975 are given in Table C11-3. For ease of comparison, various other properties at the sediment stations are also given in the table. The sand and gravel yields for the eight rivers are plotted in Fig. C11-1, and the five southern rivers are again plotted in Fig. C11-2 on an expanded scale. Figure C11-1 illustrates the absolute differences between yields of rivers, and the expanded scale in Fig. C11-2 illustrates the relative differences between the low yield southern rivers.

For the given twenty-five year period, the sediment yields for both natural and actual conditions are extremely small for the five southern rivers in comparison to the three northern rivers. The twenty-five year combined yield of sand and gravel for all five southern rivers is estimated at 383,000 tonnes for actual conditions and 2.12 million tonnes for natural conditions, giving a net deficit of 1.74 million tonnes. By way of contrast, the Santa Clara River has delivered 925,000 tonnes of sand and gravel <u>annually</u> for the twenty-five year period.

The period 1951 through 1975 has been discussed because it represents a recent period of extensive growth and development. Furthermore, in terms of sediment yield, this period is probably most directly responsible for the current status of the beaches. However, because of the extremely dry weather in the southern part of the study area for this period, the sediment yields for the southern rivers are not representative of long term yields. For example, Fig. C11-3 illustrates the effect of the extended dry weather on the sand and gravel yield of the San Luis Rey River. The natural and actual yields are shown for water years 1930 through

Table C11-3

Moderately Developed Basins: Calculations Summary

	RIVERS							
	Ventura	Santa Clara	Calleguas Creek	Santa Margarita	San Luis Rey	San Dieguito	San Diego	Tijuana
USGS Station	11118500	11114000	11106550	11046000	11042000	11030020	11022500	11013500
Basin Area (km^2)	585	4,219	837	1,927	1,450	896	1,119	4,483
Gaged Area (% of Basin)	83.2	98.9	76.7	99.5	100	87.6	87.2	99.6
Surface Bed Material								
No. of Samples	1	5	6	6	3	--	1	5
Mean D_{50} (mm)	0.43	1.03	0.44	0.35	0.26	--	0.17	0.37
Mean σ_g	7.6	3.5	1.8	1.8	1.7	--	1.6	2.1
Bed Slope at Station (m/km)	7.17	2.44	5.36	0.79	1.31	--	5.61	2.38
Average Annual Total Flow, 1951-75								
Natural (10^6 m^3)	79.2	182	12.0*	15.8	11.5	8.59	22.3	8.56
Actual (10^6 m^3)	39.8	118	12.0*	11.6	3.65	0.254	6.03	1.60
Average Annual Sand and Gravel Yield, 1951-75								
Natural (tonnes)	384,000	1,150,000	113,000	13,000	22,800	4,200	5,180-26,180	18,800
Actual (tonnes)	140,000	925,000	113,000	8,960	2,940	60	560	2,800
Actual/Natural (%)	36.5	80.6	100	68.9	12.9	1.4	10.8-2.1	14.9
Overall Rating of Sediment Yield Estimates	Good	Good	Fair	Fair	Fair	Fair	Poor	Fair

*Estimated

Note: Minor corrections have been made in this table and Figures C11-2 and C11-3 for this second printing, 11/83.

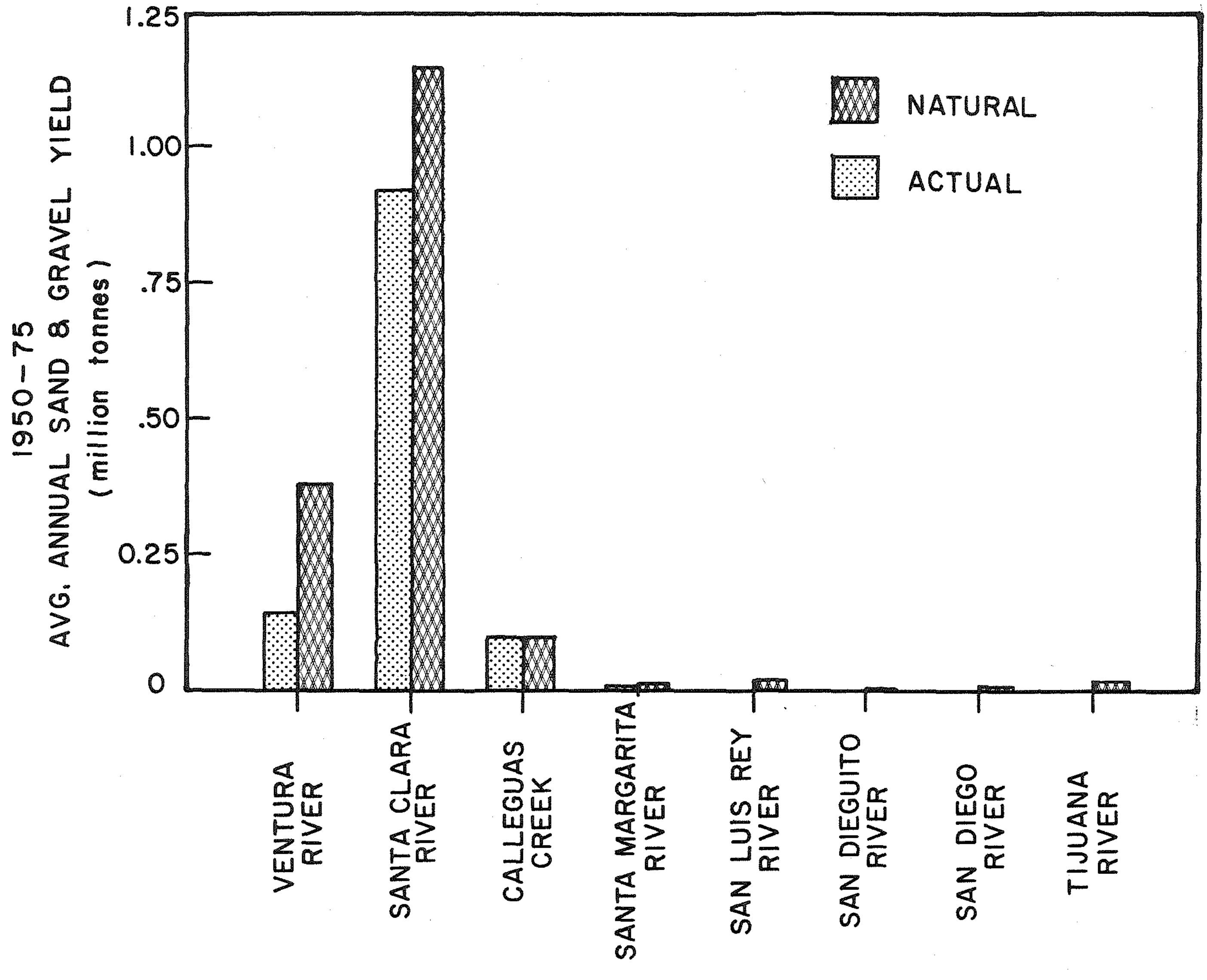


Figure C11-1 Average annual sand and gravel yield (1950-75) for the eight moderately developed river basins of southern California. See Fig. C11-2 for expanded scale for the southern rivers.

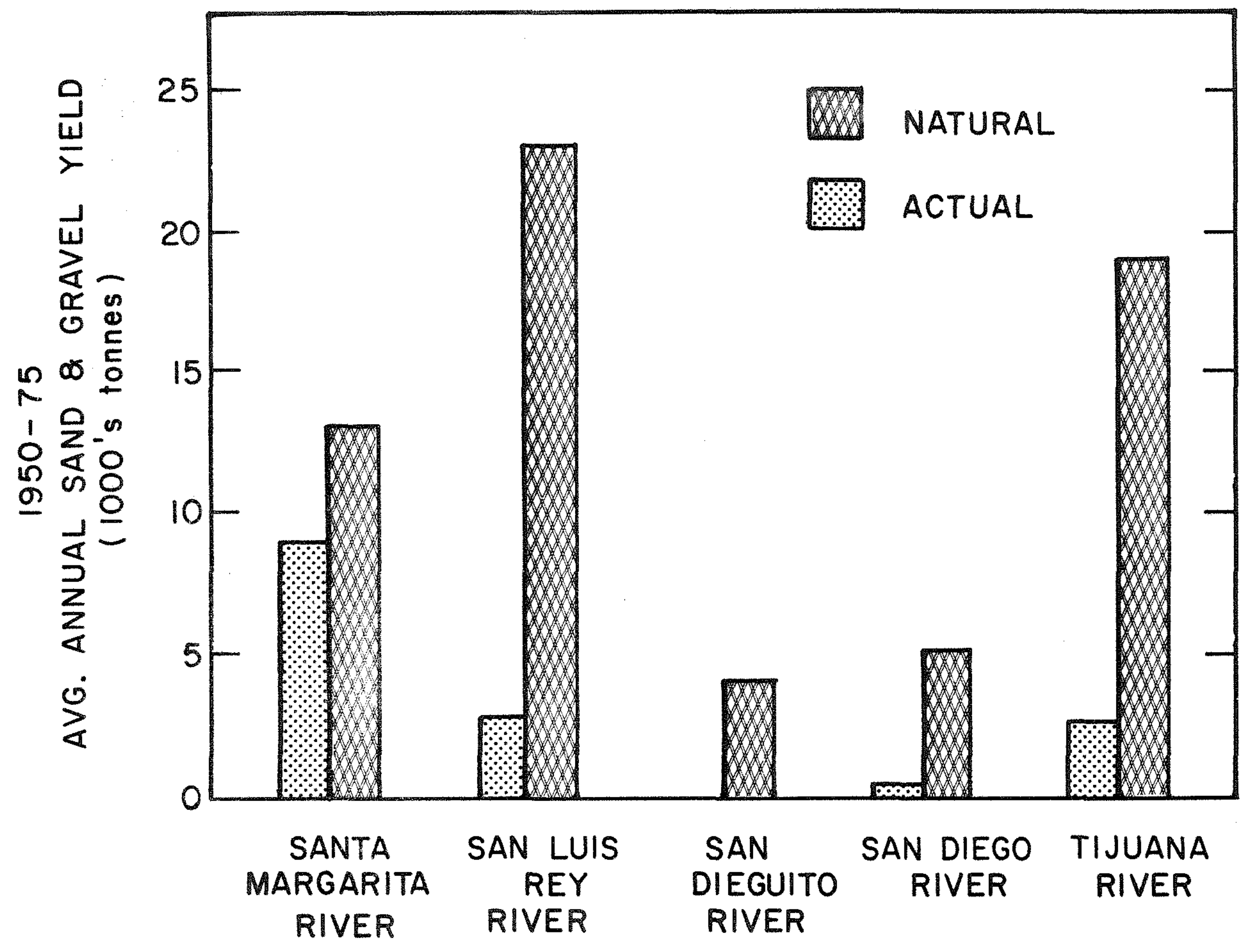


Figure C11-2 Expanded scale for the five southern rivers.

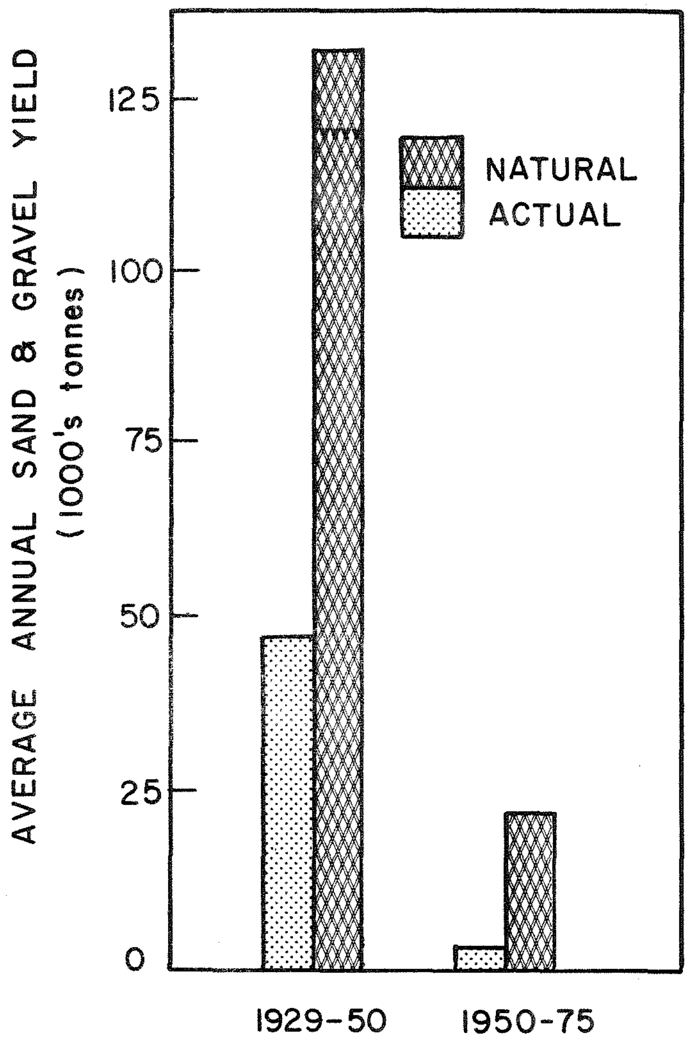


Figure C11-3 Comparison of average annual sand and gravel yields for 1929-50 and 1950-75 for the San Luis Rey River basin.

1950 and 1951 through 1975. The San Luis Rey River provides a good basis for comparison because it has been extensively controlled since 1922 by Lake Henshaw. As shown in Fig. C11-3, the average annual natural yield of sand and gravel would have been about 130,000 tonnes for the earlier period, or about 6 times that of the latter period. Similar results can be found for the other four southern rivers.

C11.2 Accuracy

It is difficult to assess the accuracy of historic sediment yield calculations. Application of the rating curves to daily flow sequences, where USGS estimates of suspended sediment discharge are available, generally gives annual yields which are within a factor of two of the USGS values. Predicted average annual suspended sediment yields for those periods differ from the USGS estimates by on the order of 25 percent or less. For the Santa Clara River, for example, the average annual actual suspended sediment yield given by the USGS for water years 1968 through 1975 (excluding 1972) is 7.64 million tonnes. Using the rating curve (Eq. C4-1) and the daily flow values gives an average annual yield of 7.37 million tonnes, which is only 3.5 percent lower than the USGS value. Although the technique predicts recent events fairly well, there is no way of checking how well the rating curve predicts annual yields historically. In general, the yields should be somewhat conservative because the mean daily flows tend to smooth short term peak flows which have high sediment discharges.

Delta and reservoir surveys provide a means of comparison for average annual historical yield calculations. Sediment yields calculated from delta surveys reported by Herron and Harris (1967) have shown close agreement with sand and gravel yields from present calculations for the Ventura and Santa Clara rivers. Furthermore, reservoir surveys have indicated good agreement between the amount of sediment stored behind dams and the difference between natural and actual total sediment yields for the Ventura, Santa Clara, San Luis Rey, and Tijuana rivers. For the San Diego River, agreement with survey data is not good and therefore, a range has been given for the natural sand yield in Table C11-3, for this river. Discrepancies on the San Diego River are not totally unexpected because of a number of reasons discussed in section C9.9, which are not associated with other rivers.

From the comparisons discussed above and the number, range and consistency of sediment discharge samples, a qualitative assessment of the sediment yield calculations for each river is given in Table C11-3. Much of the uncertainty on the southern rivers stems from the lack of particle-size analyses of concentration samples, and the limited discharge range of concentration samples on the San Diego and Tijuana rivers. The main problem for Calleguas Creek estimates is the lack of historical discharge data.

C11.3 Closure

Estimates of historical sediment yield for the eight moderately developed basins have shown extreme variability over several orders of magnitude both in time and from basin to basin. Uncertainties in the calculations on the southern rivers illustrate the need for suspended sediment concentration samples and particle-size analyses at high discharges for these rivers.

The extensively developed basins of southern California are discussed in Sections C12 through C14. The techniques for estimating sediment yields of the moderately developed basins are, in general, not applicable to the extensively developed basins. However, by using various types of survey data, rough estimates have been made of natural and actual average annual sediment yields.

EXTENSIVELY DEVELOPED BASINS

By

Brent D. Taylor

C12 Extensively Developed Basins - Introduction*

Within the coastal drainage of southern California, surrounded by western Traverse Range Mountains on the north and east and the Peninsular Ranges to the south, lies a large extended basin. This basin and its associated upland catchments is drained primarily by three major rivers -- the Los Angeles, San Gabriel, and Santa Ana, whose combined drainage area totals 8,200 km^2, or about 25 percent of the southern California coastal drainage.

Figure C12-1 locates the natural stream courses in inland valleys and coastal plains around 1920, prior to most of the present artificial control facilities, and also identifies channel areas that the rivers had used previously.

In reports prepared by the Los Angeles Flood Control District in 1915 and the U. S. Geological Survey in 1942, the basin rivers were described as follows:

> "The crest of the (surrounding) coast range, whose elevations average from 5,000 to 10,000 ft (1,500 to 3,000 m) is but fifty miles (90 km) inland so that the drainage lines of the (rivers) are short. Normally, they have sharp and precipitous gradients in their canyons debouching upon detrital cones extending over gravel filled valleys, finally crossing the flatter floor of the coastal plain and entering the sea. The gradients of these streams change violently. The steeper gradients of the mountainous portion break into the gentle slopes of the valleys and coastal plains. Their courses are unstable due, among other

*Sections C12-C15 on the extensively developed river basins were written by Brent D. Taylor, with subsections on geological setting by Theresa W. Fall.

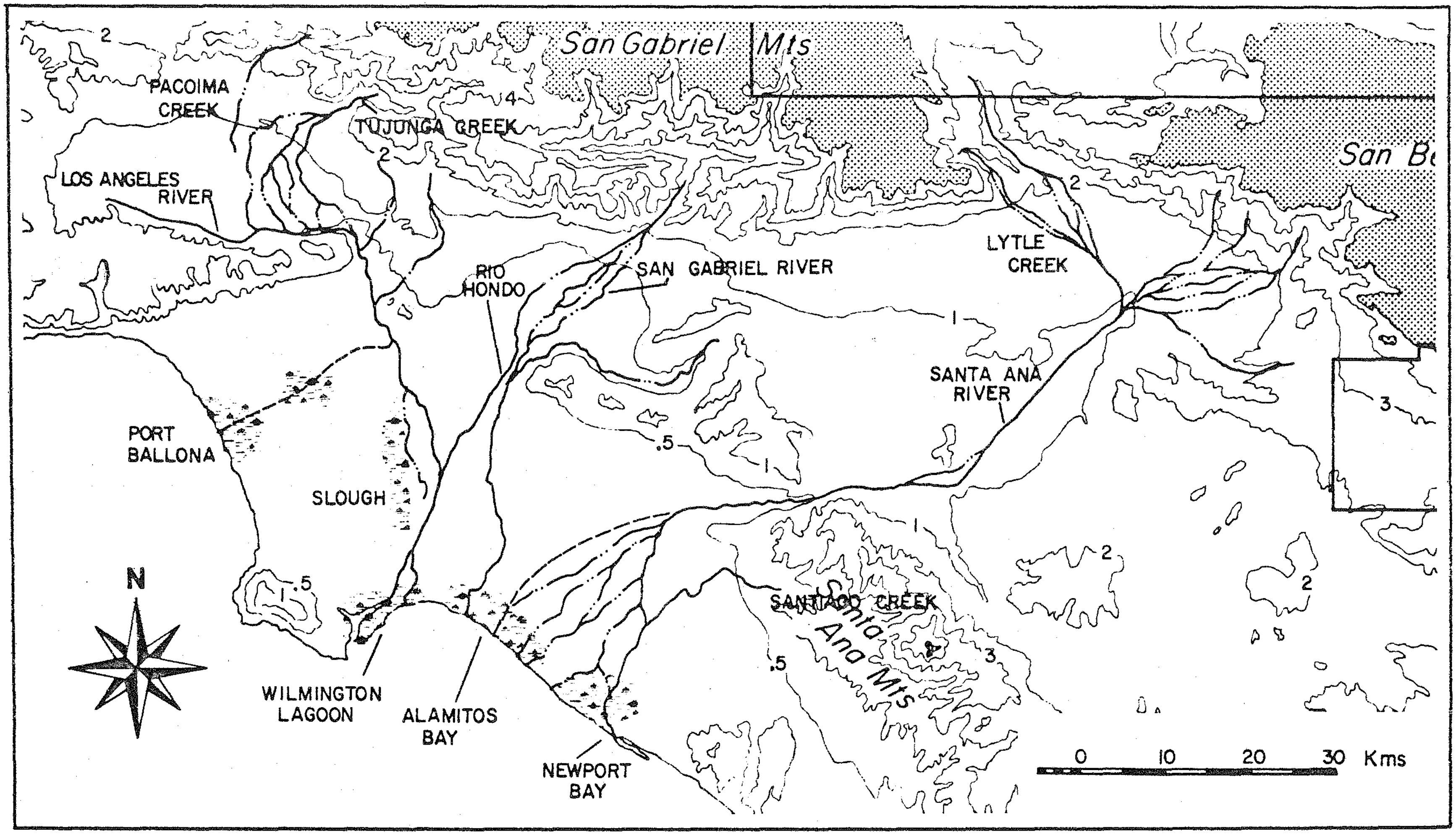


Figure C12-1: Natural Historical Channel Courses of the Los Angeles, San Gabriel and Santa Ana rivers prior to artificial controls.

causes, to the natural building up of delta-like fans. Because of these detrital deposits, the streams raise themselves above the surrounding country and in flood break their banks and make for themselves new channels."

(Los Angeles County, 1915)

"There is considerable evidence to show that the (three rivers) have, in the past, meandered over a large part of the (coastal plains). It is known, for example, that within historical time the Los Angeles River has reached the ocean through Ballona Creek. During the same period the San Gabriel River has shifted several times between its present channel, the bed of the Rio Hondo, and the former course of the Los Angeles River. The Santa Ana River, also, has occupied several channels within an area extending from Anaheim Creek to Newport Bay. Thus the lower part of the coastal basin is in reality a flood plain fed by the flows of these rivers, and in times of high flood discharge it is not unusual to find free intermingling of their waters in a sheet spreading across the lowlands between Anaheim ... and the ocean."

(Troxell, 1942)

This extended basin contains the largest contiguous valley/plain area which opens to the ocean in coastal southern California. Therefore, it is not surprising that this area has been the most heavily developed. It also contains the most extensive water conservation and flood control system (see Plate D2-1 in Report 17-D).

A variety of factors, natural and man-made, combine to make shoreline sediment delivery by these three rivers difficult to quantify. Natural surface flow characteristics are complicated by the size of the drainage basins and their varied geology. There is also an enormous range of natural river discharge values; low and moderate annual flows are punctuated every few years by extreme flood flows during severe winter storms. For example, a streamflow gage located along the Santa Ana River near the city of Santa Ana has on record no-flow for an entire water year, and then almost 500 million m^3 of discharge in 1969.

Available surface flow is heavily utilized for municipal, agricultural, and industrial purposes; and continual changes in water rights, due in part to litigation, have been an integral part of the past 120-year history of the rivers. A USGS hydrologist writes of the Santa Ana River:

> "Probably no other stream of its size in the United States is made to serve greater or more varied uses. To begin with, a portion of the flow is regulated by artificial storage in the upper part of the basin, and the water passes successively through three hydro-electric plants before reaching the mouth of the canyon. On leaving the lower plant it is turned into high-level canals and used for municipal supply and irrigation...the irrigation water that escapes through seepage to the body of groundwater is recovered from springs and flowing wells, and from pumped wells, and is used for irrigation around San Bernardino and Riverside...Bedrock obstructions at Riverside Narrows force to the surface a part of the water in the gravel bed of the stream above this point, and this water after being diverted for power development is returned to the river. Only a few miles below

> it is again diverted and used for irrigation on the coastal plain in the vicinity of Santa Ana and Anaheim. The seepage water from irrigation is once more recovered by numerous pumping plants and flowing wells on the lower coastal plain. It is thus evident that the same water, in passing from mountain to sea...may be used at least eight times."
> (USGS, 1913)

Since this was written in 1913, large scale changes in land use in the basin have altered runoff and the sediment yielding character of the landscape and placed even greater demands on surface and groundwater supply.

On all three river drainages, farming has given way to dense urbanization in valley and coastal plain areas resulting in increased needs for municipal and industrial water supply. Extensive systems for water conservation and importation have been developed to ensure adequate water supplies. At the same time a variety of flood control projects have been built along the rivers and their tributaries to protect the populace and property from storm flows and local sedimentation. Finally, artificial controls also involve the sizable transfers of groundwater to surface waters and vice versa (percolation basins).

With each of the three rivers, surface flows were severely perturbed by man before streamflow data sufficient to define natural conditions had been obtained to identify man's effects on streamflow and shoreline sediment delivery. Therefore, techniques used to analyze the "moderately developed basins" treated in sections C2 to C11 cannot be applied to these three rivers. Natural versus actual sediment deliveries must be inferred from limited historical information and data which vary with each river.

In Section C13, the Los Angeles and San Gabriel rivers are discussed synoptically. This format was adopted because these two side-by-side basins are connected naturally and now artificially, along their main channels. Also, complementary information and data are available for the two rivers, and their respective periods and present extent of human development closely parallel one another.

The Santa Ana River is the longest and probably the most complicated drainage in the study area. It is complicated by natural conditions as well as the long-time and varied artificial controls. In this respect, it serves as an example of the varied conditions that can be obtained on other rivers in the region, and for this reason, it is given a more extensive descriptive treatment.

While the format for discussion of these rivers is not the same as that followed in sections C2 through C11 for the moderately developed basins, the objectives are the same: To provide a description of the natural system, the historical development and present levels of artificial controls. Then with available data obtain estimates of annual shoreline sediment deliveries, especially sand-sized material, under natural and actual conditions during recent decades.

Extensive debris storage records are available for the upland areas of these river basins. Since upland sediment processes are the subjects of Report 17-B, these data have not been included here. It is anticipated that anlyses of upland processes and coastal processes will be integrated in the summary report.

C13 Los Angeles and San Gabriel Rivers

C13.1 Drainage Basin Description

The Los Angeles River originates in the Santa Susanna and Santa Monica mountains bordering the westerly portion of the San Fernando Valley (see Fig. C13-1). Tujunga, Pacoima, and other smaller creeks whose sources lie in the western San Gabriel Mountains northeast of the City of Los Angeles join the river as it flows easterly a distance of 36 km along the south side of the San Fernando Valley and then cuts 11 km south-easterly around the eastern terminus of the Santa Monica Mountains (Hollywood Hills). Except in times of excessive flood, tributary waters naturally disappeared in the sand and gravel washes of the Valley. Between the Hollywood Hills and the neighboring Verdugo Mountains to the east, in the Los Angeles Narrows bedrock forced the water back to the surface forming what was originally known as the Los Angeles River. It was because of this "natural spring" that Puebla de Los Angeles was originally located near this point more than 200 years ago. Below here, the river flows south onto a broad coastal plain. Near the present Civic Center, the river is joined by the Arroyo Seco, another major tributary. The Arroyo Seco flows from its upland source in the San Gabriel Mountains, over a wide river bottom of coarse alluvium for more than 3 km. The percolation capacity of this material is high, and natural streamflows were greatly diminished.

The Los Angeles River has not always had its present course. Kenyon (1951) writes:

> "Early Californians, including Pio Pico, last Spanish governor of Alta, California, have been recorded as stating that prior to 1825 the Los Angeles River discharged southwesterly through Ballona Creek into Santa Monica Bay. A severe flood that year is credited with having changed the direction of flow, and the

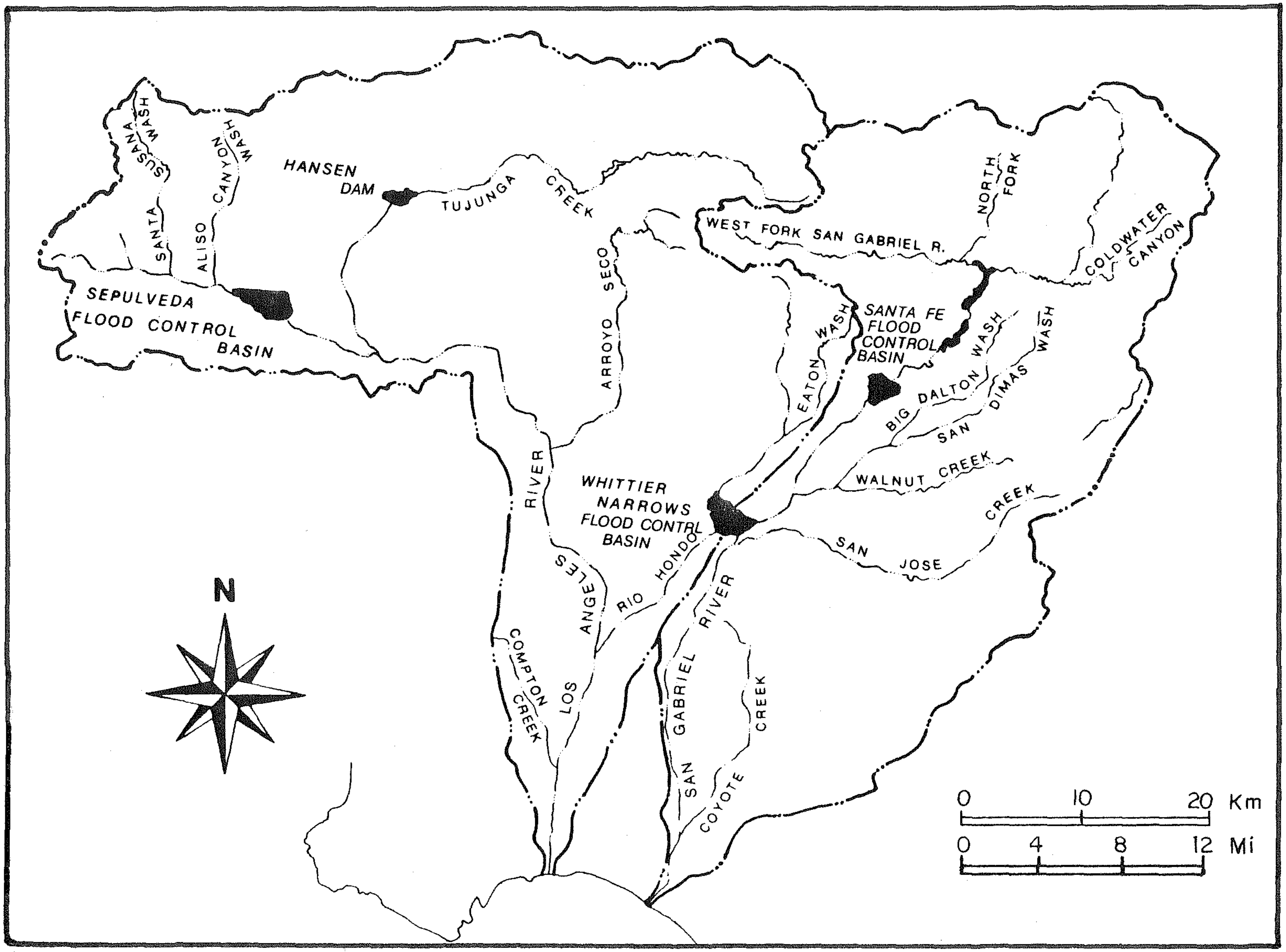


Figure C13-1 Los Angeles and San Gabriel river basins under present conditions with primary controls identified.

> discharge of the Los Angeles River has since been in a southerly direction."

During the floods of 1862 and 1884, part of the flood water returned to the old course, and some flowed eastward to the San Gabriel River. But since 1884, all of the discharge has been southward to San Pedro Bay.

Again from Kenyon:

> "Prior to January 1868, the Los Angeles River joined the San Gabriel River about seven miles (13 km) north of San Pedro Bay. A flood which occurred during that month split the waters of the San Gabriel River above what is now known as Whittier Narrows and diverted a considerable portion into a new channel which discharged into Alamitos Bay, some six miles (11 km) down coast from the old outlet into San Pedro Bay. Thereafter, the name 'Los Angeles River' was gradually applied to the lower reach of the old San Gabriel River and the new San Gabriel River became known as 'San Gabriel River.' Thus, the Los Angeles River acquired an official outlet to the ocean at San Pedro Bay, although still receiving through the interconnecting stream, the Rio Hondo, an appreciable percentage of the discharge from the San Gabriel River..."

From 1862 to 1922, the natural point of discharge to the ocean was located in the shallow drowned valley at Wilmington, in the rear of the shoreline of San Pedro Bay, at the present site of the Los Angeles inner harbor (see Fig. C13-2). The Wilmington area was at that time representative of a drowned valley in the latter stages of alluviation from debris delivered by a river system.

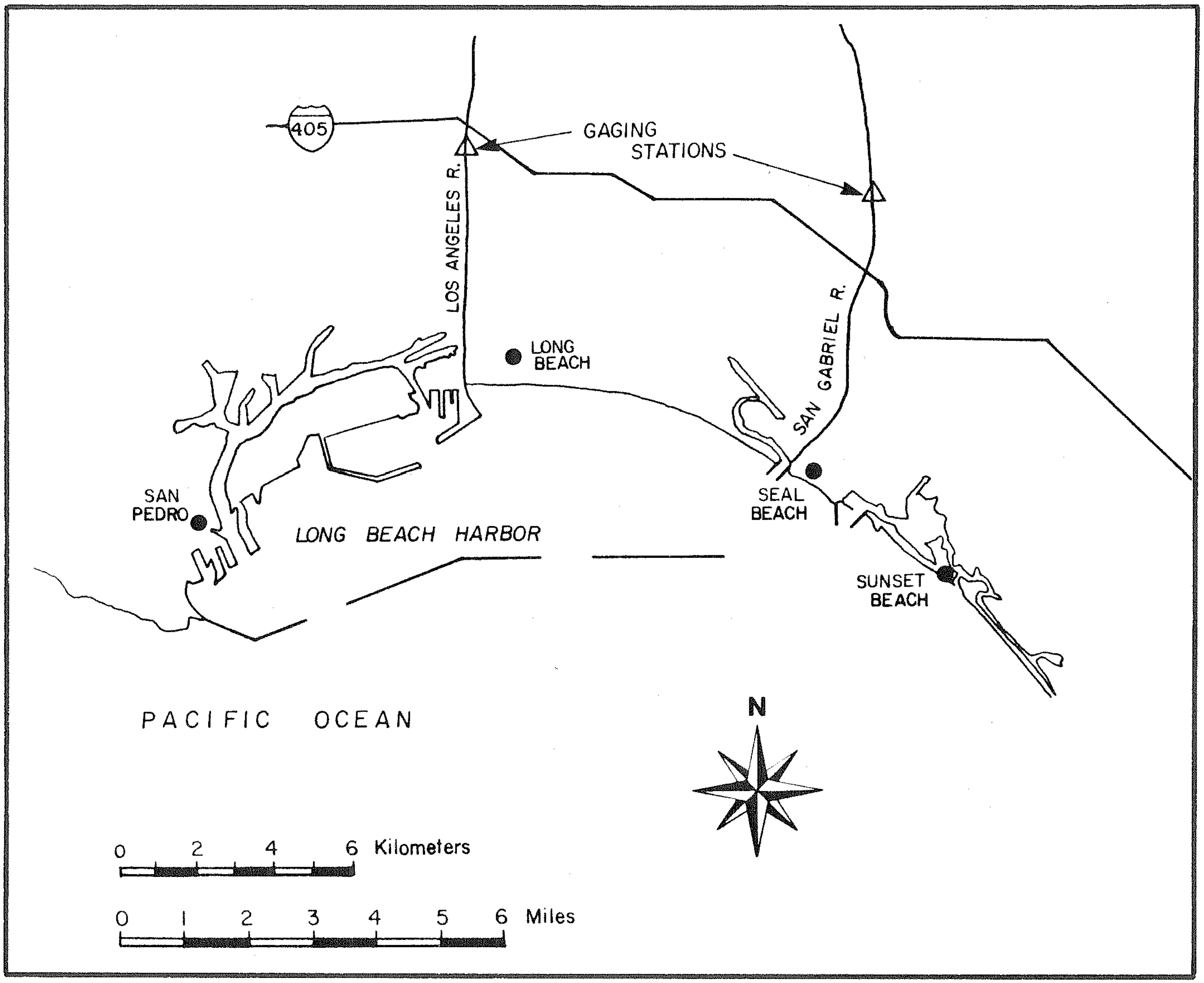


Figure C13-2 Outlets of Los Angeles and San Gabriel rivers under present conditions.

The Los Angeles River basin at present has a total drainage area of 2,155 km^2, about 850 km^2 are upland catchments with elevations ranging up to 2,100 m in the San Gabriel Mountains and to 900 m in lesser ranges. The remaining 1,250 km^2 are low foothills, valley floor, and coastal plains.

The main stem of the river is about 90 km in length. River slopes over this distance are around 0.003, 0.006, and 0.04, respectively, for the coastal plains, San Fernando Valley, and larger upland tributaries.

Between the old river mouth in Santa Monica Bay and the Palos Verdes Hills, El Segundo sand hills stretch for 21 km along the coast and form an interesting geomorphic feature. These hills consist of two belts. One belt two-thirds to one km wide extends along the shore to Redondo Beach and is composed of dunes whose crests rise 25 to 60 m above sea level. The second belt just inland is composed of sand hills and stable dunes of Late Pleistocene age (less than 1 million years). The highest crests are 75 m above sea level, and this belt is from 4 to 9 km wide. Most of the sand hills have an elongate form and parallel the coast. Each of these belts may have at one time been offshore bars, modified subsequent to their emergence.

The San Gabriel River basin lies between the Los Angeles River to the west, and the Santa Ana drainage to the south and east (see Fig. C13-1). In this location it drains the central segment of the San Gabriel Mountains which rise to over 3,000 m in this area. From the crest of the San Gabriel Mountains to the Pacific, the river course covers some 90 km. Its total drainage area is 1,663 km^2, with one-third of this area in the San Gabriel Mountains. The remaining two-thirds of the drainage includes the San Gabriel Valley at the base of the mountains, and the coastal plain below this valley.

The river originates with two opposing forks, one from the east and the other from the west, in the San Gabriel Mountains. The two forks, which lie along a fault zone, join about 14 km above the mouth of San Gabriel canyon.

After leaving the mountains, the general course of the river is southwest. It courses the San Gabriel Valley for 25 km over a wide wash of sand, gravel, and boulders, and then flows through the range of foothills separating this valley from the coastal plain at a gap called Whittier Narrows. Prior to 1868, the river flowed 36 km on the coastal plain to enter the ocean through low marshy tidelands at Alamitos Bay, a few km east of the present City of Long Beach. The low marshy tidelands at the mouth were susceptible to total inundation during floods.

In 1868, the river cut a new channel to the ocean upcoast and between then and 1931 when channelization began, the river mouth migrated less than 1 km.

The San Gabriel River has always flowed through Whittier Narrows. However, at a point somewhat north of there it had from time to time branched into two streams, one channel now being known as the Rio Hondo and the other as the San Gabriel River. The Rio Hondo joins the Los Angeles River about 11 km south of Los Angeles, and 32 km below where it leaves the designated San Gabriel River channel. The natural course of the latter is into Alamitos Bay, though it has at times followed closely the present course of the Rio Hondo, and joined the Los Angeles River near the coast.

In the San Gabriel basin, elevations range from sea level to 70 m on the coastal plain, from 70 to 500 m in the San Gabriel Valley, and up to 3,000 m in the mountains. The mountainous topography is rugged, especially in the upper part where steep, narrow canyons exist.

Mean annual precipitation in this basin and the Los Angeles River basin ranges from 35 to 50 cm in the valley and plains areas, and from 50 to 120 cm in the mountains. It occurs almost entirely as rain except on the higher peaks, where snow falls at times during the winter. On the northern slopes, this snow often remains for several weeks.

C13.2 Geological Setting

The Los Angeles River drains the western San Gabriel Mountains, parts of the Santa Monica Mountains and the Simi and Santa Susanna hills, all of which rim the San Fernando Valley. The exposed rocks of the San Gabriel Mountains are highly fractured Precambrian gneisses and schists which have been intruded by granodiorite, monzonite, and other granitic rocks, primarily during Mesozoic time (65-225 million years ago). These rocks have been continually uplifted since early Tertiary time (25-65 million years ago) and, consequently, have supplied surrounding basins with granitic and metamorphic material. During the uplift of the San Gabriel Mountains, shallow seas inundated areas to the south and west, depositing thick marine sedimentary sequences in both the Los Angeles basin* and the Ventura basin. Later, tectonic activity in the area uplifted the marine sequences to form the Santa Monica Mountains, Simi Hills, and the Santa Susanna Hills.

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*The Los Angeles River basin is not to be confused with the Los Angeles basin. The Los Angeles River basin refers to the drainage area of the Los Angeles River. The Los Angeles basin refers to the present physiographic basin and a much older physiographic and depositional basin which has received sediments for the past 20 million years. The present physiographic Los Angeles basin is bounded on the north by the Santa Monica Mountains and the Elysian, Repetto, and Puente hills and on the east and southeast by the Santa Ana Mountains and San Joaquin hills. The older physiographic basin extended northward into the San Fernando Valley and bordered with the Ventura basin.

Since subsidence of the Los Angeles basin began 20 million years ago, more than 10,000 m of sediments have accumulated at some locations. The Los Angeles basin is replete with folds and faults (as shown in Plate A-3, Report 17-A). This basin is one of the rare areas where folds are so youthful that complete forms are easily distinguishable in the topography. The youthfulness of the folds is also demonstrated by stream antecedence. In most areas of varied topography, the rivers are young, geologically speaking, and flow around these general topographic features (mountains and hills). In areas where the streams precede the uplift and uplift is slow, the streams are able to cut down and maintain their course. Stream antecedence is demonstrated in the downcutting of the Los Angeles River across the Elysian Park anticline and in the Dominguez Hills (see Fig. C13-1 and Plate A-3). Stream antecedence is also evident on the San Gabriel River in its downcutting through Whittier Narrows.

All of the structural features within the basin trend northwest, with the exception of the east-west Santa Monica-Raymond Hill-Foothill fault zone which forms the northern border of the present Los Angeles basin (see Plate A-3). The Whittier fault and the Newport-Inglewood fault are the largest within the basin. The Whittier fault is a northerly extension of the Elsinore fault system, which extends southeast through the Peninsular ranges. The movement along this fault is both right lateral and vertical, with a total oblique displacement of 4,600 m. The Newport-Inglewood fault, which is seismically active, has produced 1,200 m of differential vertical relief in the basement rocks of the Los Angeles basin, and there is also evidence to suggest considerable right lateral displacement.

The east and west tributary forks of the San Gabriel River in the central San Gabriel Mountains flow down a linear trough eroded along the San Gabriel fault zone. The San Gabriel fault dominates the structure of the San Gabriel Mountain range. This reverse fault has uplifted the mountain range to the north and has a right lateral displacement of four miles. It appears that the most recent movement occurred during Early Pleistocene (2 million years ago). The southern boundary of the San Gabriel Mountain range is bounded by the Sierra Madre fault zone. Uplift on the northern side of the many low-angle, north-dipping reverse faults within the zone has been as much as 600 m, with the most recent activity along the fault occurring some 1 million years ago.

C13.3 Control Facilities

It is probably safe to say that for its size, the Los Angeles River has the most extensive system of controls of any river in the world. Within a drainage area of 2,155 km^2, there are 290 check dams, 75 debris basins, 8 flood control and storage reservoirs, two larger flood control basins, and percolation basins totalling several square kilometers, with complete channelization of the drainage network except above the mouths of upland catchments. Figure C13-3 schematically illustrates the present configuration and control facilities on the Los Angeles River (see also Plate D2-1, Report 17-D).

The history of controls on this river dates back to 1889 when a minor stream avulsion below the City of Los Angeles during a flood flow was attributed to the presence of a partially confining channel within the city that was constructed between 1884 and that year.

The approximate location of the mouth of the Los Angeles River during the 90 years following the flood of 1825 was near the present east basin of Los Angeles Harbor at the end of Terminal Island. During this time, the Los Angeles Harbor assumed an ever increasing role in the welfare of the County. Hence, when the flood of 1914

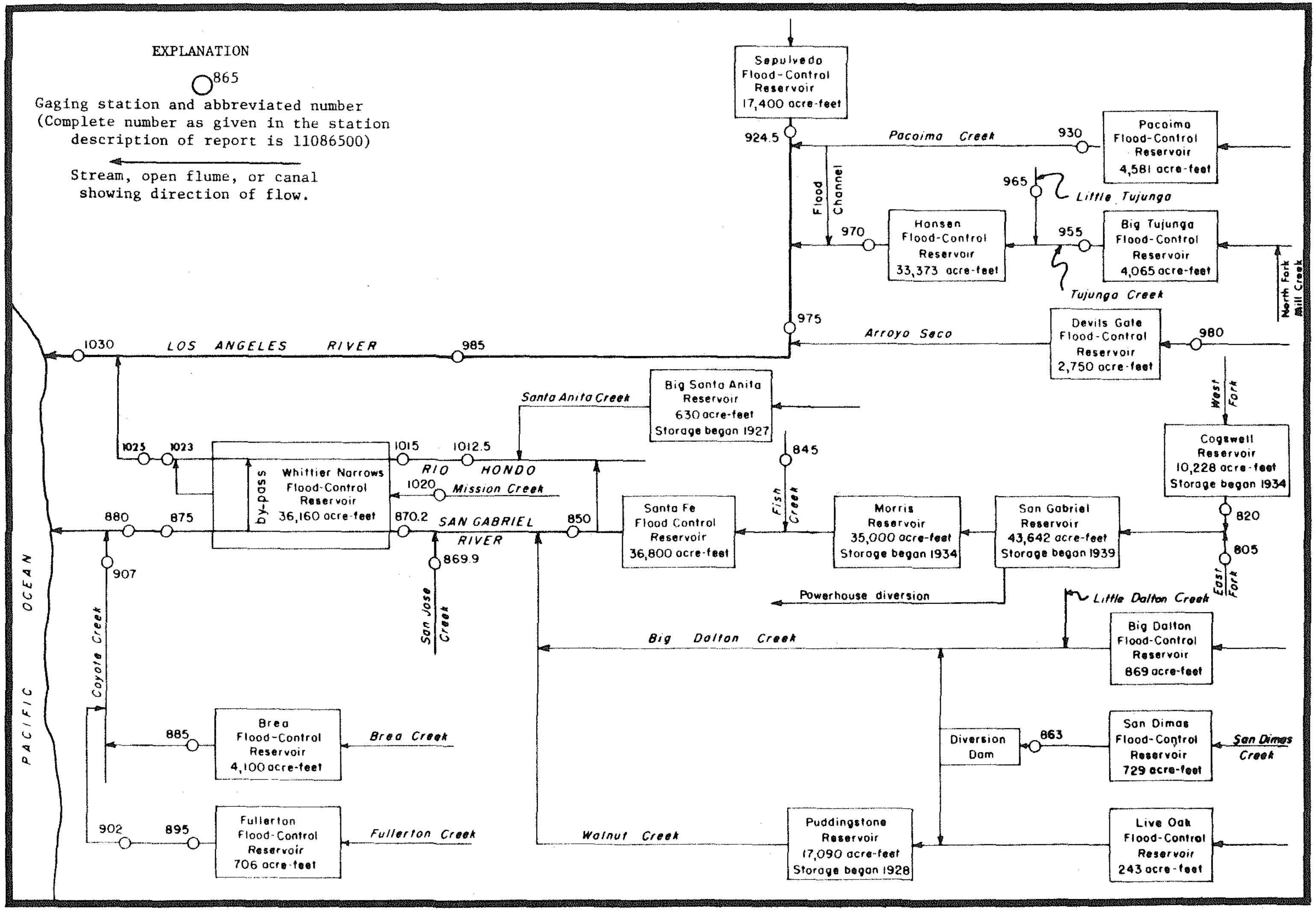

Figure C13-3 Schematic diagram of present configuration of Los Angeles and San Gabriel rivers (after USGS).

discharged several million cubic meters of sediments into the dredged areas of the harbor and a smaller volume in the dredged areas in Long Beach Harbor, federal funds were used for the construction of a channel to carry river discharge to the ocean just east of Long Beach Harbor. This improvement, completed in 1921, provided a trapezoidal channel with a base width of 160 m, from the outlet due north approximately 8 km through the City of Long Beach to an intersection with the natural channel upstream.

After the floods of 1914 and 1916, upstream flood control facilities began to be considered in earnest. Then beginning in the 1920's, there came a 20-year period of extensive construction.

Since about 1940, there has been additional construction. For example, during this time the U. S. Forest Service has constructed hundreds of small channel-debris retention structures called "check dams." The intended purpose of these structures has been to reduce debris production from erosional areas by stabilizing stream channels and adjoining hillslopes.

Also, after 1940, Hansen and Sepulveda Flood Control basins were built, and the channelization of the Los Angeles River was completed.

In addition to changes in land use and artificial river controls, for several years the City of Los Angeles has stored imported water (Owens River Aqueduct) in the San Fernando and Chatsworth reservoirs and at times discharged this water for conveyance downstream.

Second only to the Los Angeles River, the San Gabriel is the most heavily controlled river in southern California. Within its drainage there are 38 smaller check dams, 16 debris basins, 8 flood control and storage reservoirs, two larger flood control basins, several artificial percolation basins, and near-complete channelization below the mountain catchments.

The present configuration of the San Gabriel River and the locations of major control structures are shown schematically in Fig. C13-3 (see also Plate D2-1, Report 17-D).

The chronological advent of these structures closely parallels those along the neighboring Los Angeles River. It is interesting that with the advent of control facilities, the drainage from two small catchments, Live Oak and Thompson creeks, near the eastern border of the present San Gabriel drainage which were originally tributary to the Santa Ana River, were diverted to the San Gabriel system.

In the late 1920's, the Los Angeles County Flood Control District improved the lower reach of the San Gabriel River by straightening and widening the channel. This improvement terminated at the intersection with the natural channel of the river approximately 1,200 m inland from the ocean. The natural course of the river below this point was tortuous and discharged into the eastern end of Alamitos Bay some distance west of the Bay's outlet to the ocean.

During the 1930's, the river was straightened and channelized from the improved section south to Alamitos Bay and the ocean. Then, in 1944, a separate entrance to Alamitos Bay was constructed, including the separation of the San Gabriel River outlet from Alamitos Bay.

During the past 50 years, there has been a surface subsidence in the area near the outlets of the Los Angeles and San Gabriel rivers. Near the mouth of the San Gabriel surveys by the Los Angeles County Flood Control District indicate a subsidence of about 0.4 m. At other locations in the area net subsidences of several meters have been measured. It is believed that this subsidence has been caused by oil withdrawal from subsurface sedimentary strata.

C13.4 Gaging Stations

Currently, the USGS publishes discharge records at 16 gaging stations on the Los Angeles River system. However, the periods of record, even for older stations along the lower reach, began only after there had been significant upstream development. Therefore, because of the large-scale changes in land use and controls during this period, it is not possible to identify the natural flow regime from available data as was done with the moderately developed river basins.

While there have been a large number of measurements of debris accumulations behind retaining structures in the river system, systematic sediment discharge measurements were not begun until water year 1976. In January of that year, the USGS established the only sediment discharge station on the river, in conjunction with a stream gaging station (11103000) 6 km inland from the mouth.*

Streamflow data on the San Gabriel River are available at a number of locations. But along the lower reach these data extend back only to 1927, after significant development had begun.

In January of 1976, the USGS established the only sediment discharge measurement station on this river, in conjunction with the streamflow station nearest the ocean (Station 11088000). However, with the present high level of development and controls on the San Gabriel and Los Angeles rivers, the recent sediment discharge data do not characterize relations between sediment discharge and streamflow under natural conditions. Also, with the present level of development having come about graudally over the past 50 years, these data do not correctly characterize the relations between streamflow and sediment discharge during most of this period of development. Thus, available sediment discharge data cannot be used to identify natural coastal sediment yield on any time frame, or actual yield for more than a decade.

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*Fifteen unpublished suspended load measurements (1973 to 1976) had been made at this station.

C13.5 Stream Bed Characteristics

The channel of a river is defined by its planform, cross-sections, changes in elevation or slope, and bed materials. Figure C12-1 provides a map of the general planform of the Los Angeles River before 1920, but a more complete set of natural channel data during this early period are not available for either the Los Angeles or San Gabriel rivers.

Figure C13-4 gives a profile of the river bed from its mouth inland to its official source, under present conditions. The river slope gradually increases from its outlet to some 30 km upstream where it becomes approximately constant for the next 40 km (typical values are given on p. C227).

With upstream reservoirs and debris basins, the fully-lined channel is swept clean over most of its length by both high and low flows. This would be expected with the artificially reduced sediment deliveries of upland catchments and increased "clearwater" runoff from the large urban areas.

In the absence of historical data, it might be assumed that, under natural conditions, channel bed materials would be similar in size to that found in the neighboring Santa Ana River. Bed material in the Santa Ana river is composed primarily of fine and medium sands, with mean sizes around 0.5 mm.

A profile of the bed of the San Gabriel River under its present configuration is given in Fig. C13-5. The river slope slowly increases over the first 10 km and then remains somewhat constant for approximately 30 km. Beginning 40 to 50 km upstream near the San Gabriel Mountain front, the slope increases dramatically as the river rises over the alluvial fan and courses the mountain canyons.

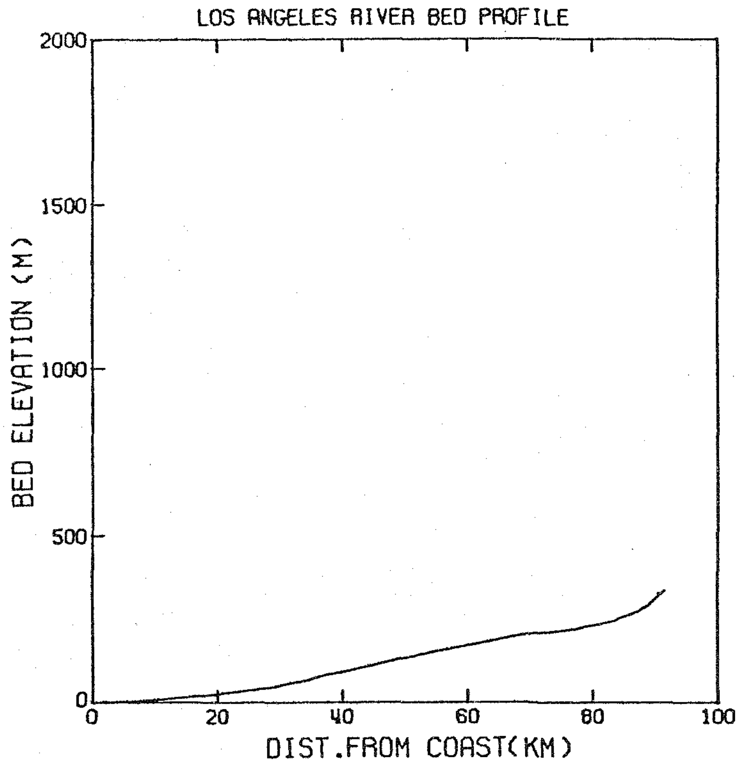

Figure C13-4: Bed Profile of Los Angeles River under present conditions.

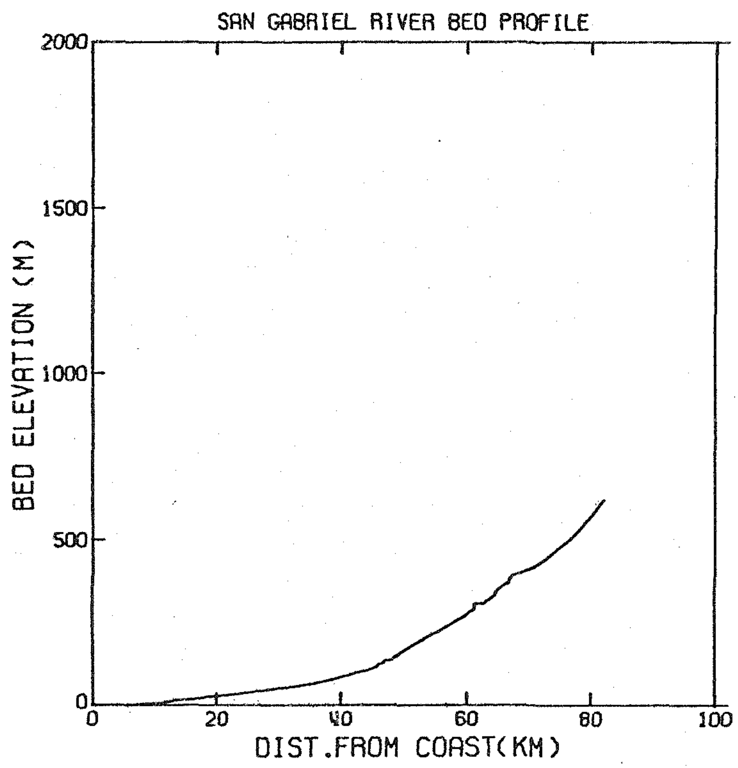

Figure C13-5: Bed Profile of San Gabriel River under present conditions.

The natural planforms of the two rivers sketched in Fig. C12-1 suggest braided planforms. The average slopes of the San Gabriel and Los Angeles rivers over the coastal plain are of the same order as slopes for braided streams identified by Leopold et al. (1964). This slope comparison also suggests a naturally braided planform for the lower San Gabriel and Los Angeles rivers under natural conditions.

C13.6 Natural Flow Characteristics

With available data, it is not possible to accurately estimate natural annual flows as was done on the moderately developed rivers. However, based upon physical characteristics of the Los Angeles River basin, characteristics of the neighboring Santa Ana River, and historical information, one can venture to estimate general characteristics of the natural streamflows. Historical information indicates that, in years of lesser storm activity with the high percolation rates and storage capacity of alluvium forming the surrounding fans and floor of the San Fernando Valley, surface flows disappeared. Much of this lost water reappeared along the river course at the narrows near the southeastern mouth of the valley. However, it is not clear whether these low and moderate-year reappearing surface flows ever reached the ocean (Ballona Lagoon in Santa Monica Bay prior to 1825 and Wilmington Lagoon in San Pedro Bay after 1825). It is probable that, in the tens of kilometers of alluvium between the point of reappearance and the coast, most of the water was again lost through percolation.

Undoubtedly, during large storms, surface flows were maintained all along the river course. The magnitude of these flows, however, can only be roughly estimated. The ratio of mountainous area to total drainage area is about the same for the Los Angeles River basin as for the Santa Ana River basin. Also, the general configurations of these two drainage basins are similar. With both, the drainage begins with multiple upland catchments. Primary tributaries join the main stem as it flows along an inland valley, the river then flows through narrows and out over a broad coastal flood plain to the ocean with some additional tributary inflow along the way.

The ratio of the drainage area for the Los Angeles River basin (excepting drainage through Rio Hondo) to drainage area of the Santa Ana River is approximately 0.5. The main channel length ratio is also approximately one-half. Since peak flows depend on factors such as channel length and slope, rainfall patterns, and dam operation, it is difficult to make direct comparisons between basins. However, even without making an extensive hydrologic analysis, the following rough comparison is of interest.

In 1938, the peak discharge in the Santa Ana River was 1,300 m^3/s with a total runoff for the February/March storm of some 154 million m^3. Assuming essentially natural conditions on the Santa Ana River during this flood, scaling by the ratio of basin areas, the natural flow in the Los Angeles River would have had a peak discharge of around 650 m^3/s and a storm runoff of some 75 million m^3. The actual peak discharge measured at Long Beach was 2,800 m^3/s with a storm runoff of more than 370 million m^3. Of this, however, 160 million m^3 came from the San Gabriel drainage down the Rio Hondo where peak discharges of approximately 850 m^3/s were measured. Thus, the peak discharge and runoff for the Los Angeles drainage alone would have been on the order of 2,000 m^3/s and 200 million m^3, respectively. These values are still larger by a factor of three than scaled estimates from the Santa Ana River. It may be that urbanization and channelization prior to 1938 increased flood flow by nearly a factor of three. It is more likely, though, that the differences are the result of subtle but important dissimilarities in the surface hydrology of the two basins, and variations in storm characteristics.

The San Gabriel drainage also lacks historical data sufficient to rigorously define the characteristics of natural stream flows. The drainage is generally similar in physiographic characteristics, as well as geological and hydrologic characteristics, to each of these neighboring river basins.

The ratio of total drainage area for the San Gabriel versus the Santa Ana River is about 0.3. Again, if intra-basin hydrologic similarity is assumed, it might be expected that with natural conditions during the 1938 flood, the San Gabriel River streamflow would have been about one-third of that on the Santa Ana River. This would give a peak discharge near the mouth of around 400 m^3/s and a runoff of 44.4 million m^3. Actual measured values were 770 m^3/s and 100 million m^3, respectively, or with Rio Hondo diversions added: 1,620 m^3/s and 260 million m^3. These values, however, are four-to-six times as large as the scaled values, probably as a result of hydrologic dissimilarities.

C13.7 Annual Sediment Deliveries to the Coast

Even under natural conditions changes in river regimen, e.g., avulsions must have produced significant sediment transport changes in the regimes of the Los Angeles and San Gabriel rivers along their lower reaches. In 1925, when the lower Los Angeles River changed its course by 90 degrees, and began to drain to San Pedro Bay, the straight-line river length over this reach increased 20 to 25 percent. With our limited understanding of river mechanics, it is not possible to accurately predict the river's adjustment vis-a-vis altered sediment transport characteristics, with this extension in length and reduced mean slope. However, it might be expected that this reduction in slope without other changes (percolation losses, bed material characteristics, etc.) would reduce sediment transport capacity for a given stream discharge and thus enhance deposition along the main channel.

Also, with the 1825 avulsion, waters of the Los Angeles and San Gabriel rivers began to intermingle. This situation was partially cancelled later by an avulsion of the upper San Gabriel creating a second active channel along the lower reach. Generally, when two alluvial streams at a given slope come together to form one stream, the sediment transport capacity of the combined flow is greater than the sum of the transport capacities on the individual streams. This would indicate that the early confluence enhanced degradation along the channels (downstream and eventually also upstream). By the inverse argument, one would expect enhanced aggradation with the later upstream bifurcation of channels along the San Gabriel River.

Perhaps the most important aspect of the 1825 avulsion of the Los Angeles River was the change affected in the location of the river's outlet to the ocean. Not only was the river mouth transposed several kilometers downcoast, but also there was a transfer of this major coastal sediment source from one littoral cell (Santa Monica cell) to another (San Pedro cell). Studies by Rice et al. (1976) have shown that there has not been notable transport of sand-sized material around the Palos Verdes peninsula under recent geological conditions.

Finally, the percolation losses of dry and moderate-year flows along the lower reaches, as well as the rivers' natural terminations in bay and lagoonal areas which serve as natural sediment entrapment areas, suggest that hydrologic variabilities in shoreline sediment deliveries were severe under natural conditions. During low and moderate years, streamflows reaching the coast deposited their sediments in the lagoons at their mouth and not at the shoreline. Much of this deposition was probably permanent, with part of the deposited material being carried on to the shoreline by major floods.

Quantitative data, which may be used to estimate annual sediment deliveries to the coast by the Los Angeles River, are limited to surveys of delta accumulation near the man-made mouth of the river during the period 1923 to 1938 (see Table C13-1). In 1927, the City of Long Beach surveyed the nearshore area and the mouth of the Los Angeles River. Then, in 1938, after the major flood of that year, the Corps of Engineers conducted a second survey in this area, and reported a deposit of 6,208,000 m^3 since 1927 within a 914 m strip of coast extending approximately 1.8 km seaward. The survey indicated that a significant part of the delta extended beyond the measurement area, and the corps estimated that the total net deposit during the eleven year period had been approximately 8,400,000 m^3.

The original Long Beach breakwater was completed in 1927, and the outlet of the Los Angeles River was inside its perimeter. Therefore, the river delta formed from 1927 to 1938 was probably not reduced by ocean currents. From a study of aerial photographs and intermittent hydrographic soundings made between 1927 and 1938, it was estimated that 60 percent of the 11-year total, or 5,046,000 m^3 was deposited during the flood of March 1938; this would suggest that the average shoreline sediment delivery for the 10 year period, 1927 to 1937, was 336,000 m^3 per year.

Similar surveys (Kenyon, 1951) were made between 1923 and 1935. The Los Angeles Flood Control District survey made in the summer of 1935 indicated a 12-year accumulation in this area of 3,440,000 m^3 for an average of 287,000 m^3 per year.

The two different surveys, 1927 to 1937 and 1923 to 1935, give annual estimates that differ by 15 percent and, considering the fact that the two measurements cover different hydrologic periods, the estimates may both be correct.

TABLE C13-1: Historical River Delta Surveys Near the Mouths of the Los Angeles and San Gabriel Rivers

River	Surveying Agency	Survey Dates	Estimated Net River Delta Accumulation
Los Angeles River	City of Long Beach/ Corps of Engineers	1927-1938	8,400,000 m^3 (5,046,000 m^3 in 1938)
Los Angeles River	Los Angeles County Flood Control District	1923-1935	3,440,000 m^3
San Gabriel River	Los Angeles County Flood Control District	1937-1938	209,000 m^3

During the 1920's and 1930's several of the large- and small-scale flood control and water conservation structures in headwater areas of the Los Angeles River drainage had been constructed, and there had also been significant urbanization along the lower reaches of the Los Angeles River by this time. Thus, the above estimates of annual shoreline delivery do not represent fully natural conditions.

It is assumed that the return period for a major storm like that which occurred in 1938 is 30 years and also that during intervening years, the average annual shoreline delivery would be around 300,000 m^3. The 5 million m^3 delta, formed by the 1938 flood, would then suggest a total annual average of 467,000 m^3. Due to the partially controlled conditions during the period of the deltaic surveys and the probability of the periodic occurrence of more severe major storms ($>$ 30-year return periods) would suggest that this estimate of average annual sand delivery of the Los Angeles River (including Rio Hondo) is conservative.

There are even fewer quantitative data pertaining to shoreline sediment delivery by the San Gabriel River. Surveys reported by Troxell (1942) for September 1937, and then following the flood of 1938 for a coastal strip 460 m wide and extending seaward 670 m from the mouth of the river, indicated a storm deposit of 209,000 m^3 of generally sand-sized material (Table C13-1).

These delta accumulation data suggest a much reduced sand yield in 1938 compared with the Los Angeles River (as was also the case with peak discharge and total runoff). Based on the ratios of drainage basin area for the two rivers, it might be expected that the sand delivery during the 1938 flood would have been around 3 million m^3.* The measurement of 209,000 is a small fraction of

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*Including sediment delivered via the Rio Hondo diversion.

this value. Some of this difference is due to the diversion of river flow from the San Gabriel to the Los Angeles river via the Rio Hondo. With twice the peak discharge and total storm flow in the San Gabriel River, such as might have been obtained without the Rio Hondo diversion based on general relations between streamflow and sediment delivery given in Section C3 to C10 for nearby rivers, one might expect a 2 to 4 fold increase in sand transport. This, however, would account for only a portion of the discrepancy. It may be that the 1937 to 1938 delta measurements on the San Gabriel River do not include total storm delivery of sand-sized material to the mouth.

If it is assumed that half of the coastal sediment delivery by the San Gabriel River flowed down the Rio Hondo diversion during the 1920's and 1930's, the combined average annual sand delivery by both rivers under natural conditions might be estimated at approximately 600,000 m^3.

With USGS suspended sediment discharge data collected near the coast on the Los Angeles River from 1973 to 1977, and streamflow data collected in 1969, a technique* similar to that employed on several of the moderately developed rivers to obtain estimates of annual sediment delivery was used to estimate sand delivery for 1969. An estimate of 1.7 million m^3 was obtained. This is one-third of the estimated sand-sized sediment delivery during the 1938 flood. In the absence of a detailed hydrologic comparison of the two similar floods, this ratio might be used as a rough indication of the relative reduction in shoreline sand delivery due to present levels of development.

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*Based on available data in this calculation, it was assumed that measured suspended sediment discharge constitutes 90 percent of the total sediment load, and that 50 percent of the sediment discharge is sand-sized material. The rating curve, based on 71 samples collected at Station 11103010, has a correlation coefficient of the lagarithms of R = 0.96, with a range of water discharges from 0.3 to 500 m^3/s (1969 flows ranged from 0.5 to 1600 m^3/s).

Finally, the available 100 year history of observed river behavior under essentially natural conditions indicates that the delivery points of streamborne sediments from the Los Angeles and San Gabriel rivers vary extremely -- from Ballona Lagoon outlet in Santa Monica Bay to Anaheim Bay several kilometers downcoast from the Palos Verdes peninsula. Thus, in addition to significantly reducing annual sediment deliveries, man has greatly affected the natural systems of these rivers by fixing the locations of their mouths along the shoreline.

C14 Santa Ana River

C14.1 Drainage Basin Description

From its headwaters in the San Bernardino Mountains, the Santa Ana River flows approximately 160 km before emptying into the Pacific Ocean just northwest of Newport Bay. The river basin covers an area of 4,406 km^2, occupying portions of San Bernardino, Riverside, and Orange counties as well as a small part of Los Angeles County. Roughly one-third of the drainage area consists of mountainous terrain. Portions of the San Bernardino, San Gabriel, and Santa Ana mountains serve as headwater areas for the primary tributaries of the Santa Ana River. Natural channel slopes in the drainage basin average around 0.05 in the mountains and 0.005 across the valley areas with values of less than 0.001 near the coast.

Basin rainfall displays a typical sensitivity to topographic features, ranging from 30-45 cm on the plains and in the valleys to 50 to 120 cm in the mountains.

Historically, the Santa Ana River has wandered over its flood plain, periodically breaching its channel during large storms and emptying into the Pacific at different locations along the coast. In the early 1800's, the Santa Ana River emptied into the ocean at Anaheim Bay near the present mouth of the San Gabriel River. The flood of 1825 shifted the mouth of the river southward, and the flood of 1884 moved it further south into Newport Bay.

The present basin area is shown in Fig. C14-1. However, the accepted basin drainage area of 4,406 km^2 does not include the area of the semiclosed San Jacinto River-Lake Elsinore basin. Overflow from Lake Elsinore enters the Santa Ana River basin via Tescal Wash. Until 1980, the last recorded overflow was in 1917 (Lynch, 1931). Controls and diversions on the San Jacinto River during recent decades have greatly reduced the possibility of this flow into the Santa Ana River. In the geologic past, the Elsinore

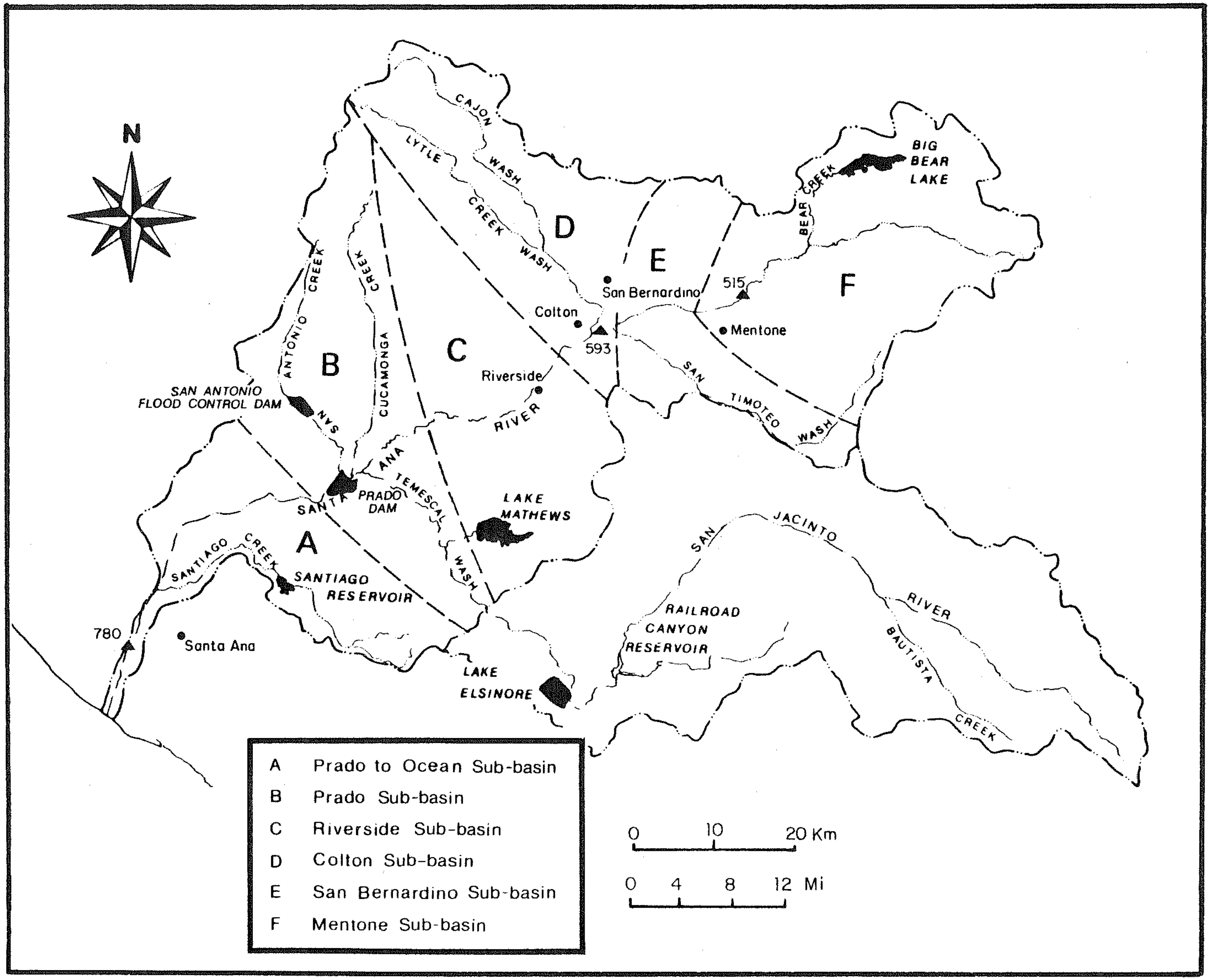

Figure C14-1 Santa Ana River basin under present conditions with sub-basinal divisions identified.

basin drained to the coast through what is now the Santa Ana Mountains. But, with intervening uplift and the inability of the drainage to maintain its westward course by channel downcutting, the basin became semiclosed with the only avenue for coastal drainage over a shallow rise between the basin and the Santa Ana drainage to the north.

C14.2 Geological Setting

Named headwaters of the Santa Ana River originate in the San Bernardino Mountains with major tributaries from the southeastern portion of the San Gabriel Mountains. The San Bernardino Mountains are separated from the San Gabriel Mountains to the west and the San Bernardino plain to the south, by the San Andreas fault zone. Exposed rocks in these two mountain ranges are highly fractured Precambrian gneisses and schists, which have been intruded by granodiorite, monzonite, and other granitic rocks, primarily during the Mesozoic era (65-225 millions years ago). These rocks have nearly continuously uplifted since the Early Tertiary period (50-65 million years ago) and consequently, have supplied coarse grained granitic and metamorphic material to surrounding basins. During the uplift of the mountain ranges from Middle Miocene (15-20 million years ago) to Early Pleistocene (2-3 million years ago), shallow seas inundated areas to the south and west, creating thick marine sedimentary sequences. Later, tectonic activity in the area uplifted the marine sequences above sea level and formed the Puente Hills.

The Santa Ana River basin is another of the rare areas in the United States where folding is geologically recent as demonstrated by stream antecedence. Had folding preceded the appearance of the river, its course would have been diverted around the contiguous topographic highs. The Santa Ana River, therefore, must have preceded the uplift and has been able to cut down and maintain its course. This stream antecedence is evidenced in downcutting of the Santa Ana Mountains between Corona and Anaheim and Newport Mesa near Costa Mesa.

The northern part of the Peninsular Ranges province extends into the Santa Ana River basin. Granitic rocks of the southern California batholith, emplaced during the Cretaceous period, 65 to 135 million years ago, and associated metamorphosed country rocks outcrop in the Santa Ana River basin with the Santa Ana Mountain range.

The Elsinore Fault zone and San Jacinto Fault zone, two of the largest in the region, trend northwest in the Santa Ana drainage and produce a series of fault-bound, down-dropped blocks. These linear horstgraben structures partially control stream courses of tributaries such as San Antonio Creek and Temescal Wash.

C14.3 Control Facilities

The Santa Ana River system is so large and complex in its natural and human aspects that it is perhaps more easily understood considering sections of the basin individually. In Fig. C14-1 the basin has been divided into six reaches for discussion of control facilities. For general reference Fig. C14-2 identifies some of the primary elements in the river system's artificial controls.

Area Above Mentone

The region around Mentone was first settled in 1851, and in the following years grew in population and in its demand for agricultural and municipal water. A large flood in 1862, possibly the largest in historical times, destroyed many existing irrigation ditches, diversion, and other controls, and altered the course of the river, reputedly increasing losses of water through percolation.

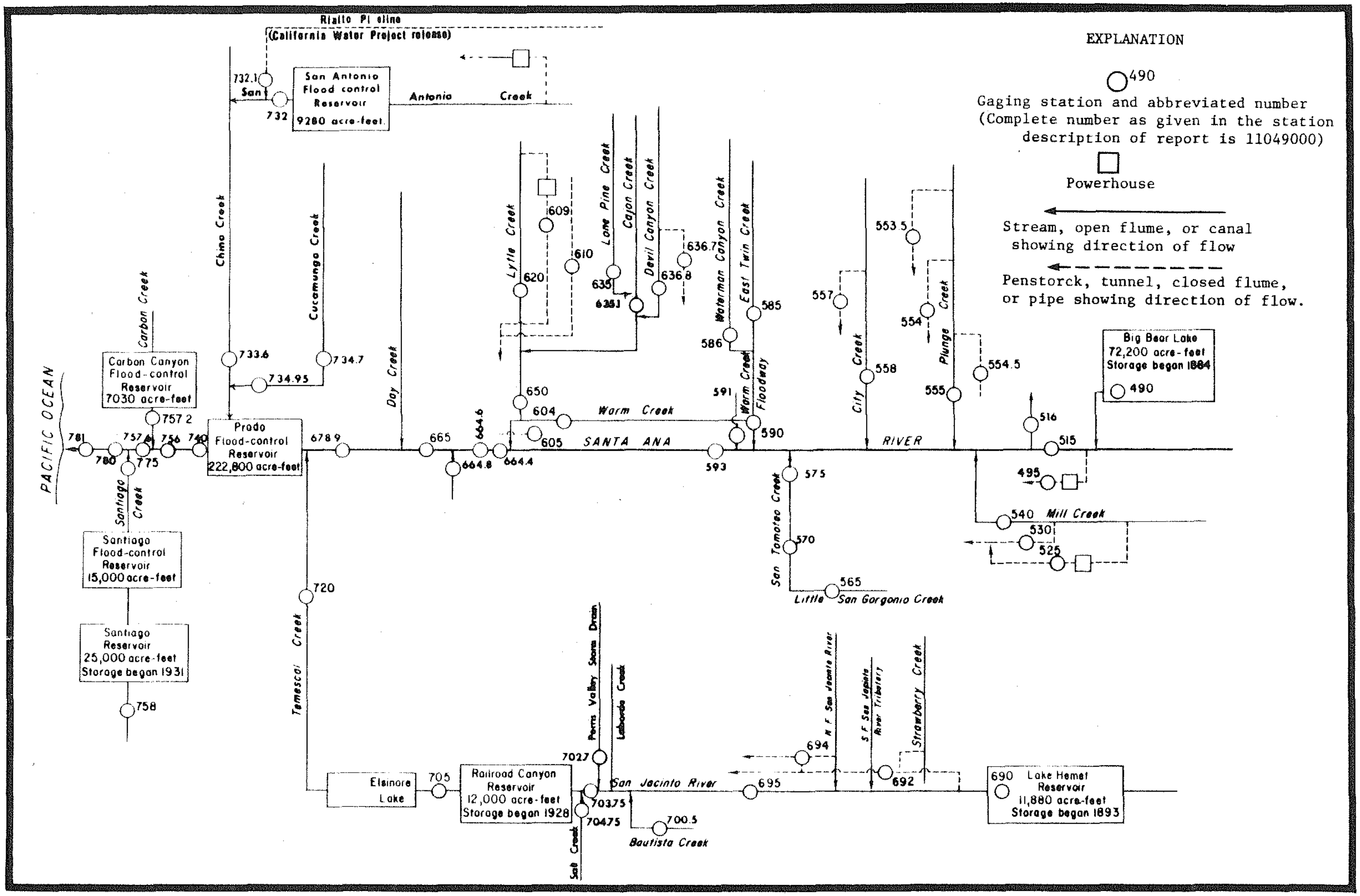

Figure C14-2 Schematic diagram of the present configuration of the Santa Ana River (after USGS).

Inadequate water supply became a serious problem, and in 1883 work was begun in upper Bear Creek on the Bear Valley Dam. Big Bear Lake was developed with an original storage capacity of 89 million m^3, and has served for water storage as well as for recreation. The reservoir typically stores between 12 to 25 million m^3 during the winter and early spring, releasing water in the summer for irrigation and power generation.

Available surface flow is heavily utilized in the Mentone area and made to serve a variety of functions. Large quantities of water are diverted above USGS station 110515000; additional quantities of water have been diverted into percolation basins for groundwater recharge.

Available data indicate that most of the surface flow is diverted along this reach. In general, only storm flows too large to be utilized by the power plant, irrigation, or percolation diversions are allowed to continue downstream.

San Bernardino Area

From Mentone, the Santa Ana River flows along a broad flat wash for about 18 km before reaching San Bernardino and USGS station 11059300.

Most of the land bordering the Santa Ana River in this area is agricultural. There are no major control structures though sizable quantities of water are diverted from the tributaries at various points for agricultural irrigation and groundwater recharge. The wash itself is composed of coarse alluvium with a high percolation capacity. The streams that empty into the Santa Ana River along this reach -- Plunge and City creeks from the north, and San Timoteo Creek from the south, lose much of their flows to natural and artificial percolation before they reach the main river channel.

Norton Air Force Base and the Loma Linda Sewage Treatment Plant discharge several hundred thousand m^3 per year into the Santa Ana River and San Timoteo Creek. Several canals head along the river on this reach, but all flow in the canals, and most of the canal flow since 1925 has been from groundwater rather than surface flow as a result of water rights litigation. Prior to 1925, most of the surface flow in the Santa Ana River, except during heavy storms, was diverted via these canals.

Colton Area

The demands for water supply and flood control along this section of the Santa Ana River, between the cities of San Bernardino and Colton have again greatly altered the natural character of the river and its tributaries. Any attempt at reconstructing "natural flows" in this area is complicated by the large variety of diversions from and discharges into the many stream channels, and unknown natural percolation rates.

Take for example Warm and Lytle creeks. Several controls alter natural flows in Warm Creek. Among these are the Meeks and Daley canals which have been diverting water for irrigation since the mid-1800's, and the San Bernardino Sewage Treatment Plant which discharged effluent into Warm Creek from 1929 to 1972. Lytle Creek is a major tributary of the Santa Ana River, though extensive diversions for hydroelectric plants and irrigation have greatly reduced its natural contribution.

There are also natural complications. Computed correlation between natural annual flows on Lytle Creek (USGS station 11062000) and Warm Creek (USGS station 11065800) is only 0.67. This low correlation is surprising since the two stations are less than 20 km apart. By comparison, Lytle and Waterman creeks, a similar distance apart, have a computed correlation of 0.97. An explanation for this anomaly lies in the unusual geohydrology of the area. The

San Jacinto fault (other faults may also contribute) forms a discontinuity in the Warm Creek area and apparently acts as a barrier to subsurface flow. Groundwater is, therefore, forced to the surface and contributes substantially to the surface flow in Warm Creek. This is probably why this locale was among the first to be settled in the area. In a typical year the amount of rising water generally ranges from 25 to 50 million m^3 while upstream surface runoff amounts to 2.5 to 10 million m^3. Only in exceptionally wet years has upstream runoff exceeded rising water.

The ability of the groundwater basin to act as a buffer against variations in surface runoff helps to explain the low correlation between annual flows in Warm Creek and Lytle Creek. Lytle Creek, as is the case with most upland streams in the Santa Ana River basin, is highly sensitive to the amount of precipitation in any given year, while a stream like Warm Creek receives a large portion of its annual flow from groundwater and behaves somewhat independent of annual rainfall.

Riverside Area

There are no significant tributaries or surface controls along the 15 km stretch of the Santa Ana River from Colton to Riverside, and one might expect the river to behave in this region. However, local flow records indicate that this is not so. Substantial flows leaving the Colton area dwindle to a trickle in the space of a few kilometers, with measured flows at USGS station 11066440 often less than 10 percent of corresponding flows upstream at Colton. A few kilometers further downstream, at USGS station 11066460, the flow increases dramatically to an amount roughly equal to the flow at Colton. Downstream of this station, the Riverside Sewage Treatment Plant discharges large quantities of effluent into the Santa Ana River and during the period 1949 to 1966, the Metropolitan Water District also discharged water along this reach.

The marked disappearance of surface flow and its subsequent reappearance downstream can be explained again by irregular geology in the area. As river flow leaves Colton, it opens onto a broad wash of recent, highly porous alluvium. The absence of upstream subsurface inflow across the San Jacinto fault renders this wash perhaps even more absorbent. Along this short reach most of the surface flow percolates naturally into the ground, leaving only a small fraction to be gaged at station 11066440. Then, further downstream, an intrusion of basement granite forces the groundwater back to the surface.

The absence of records at stations 11066440 or 11066460 during years of high flow make it difficult to identify the character of the sinking-rising water phenomenon during flood conditions. However, during the flood year 1969, there is a marked loss of water between the flow leaving the Colton area (370.5 million m^3) and the amount arriving at station 11066500 (323.7 million m^3). The "missing water" perhaps sank, overloading local groundwater storage, and was lost to neighboring aquifers.

This sinking water phenomenon has not always existed. As recently as 1934, the central stretch of the river (station 1106644) along this reach was an area of rising water with increasing surface flow rather than vice versa. Perhaps a gradual lowering of the groundwater table due to increased pumping or the recent dry period beginning in the 1940's has led to sinking rather than rising water.

Prado Basin

Prado Dam, completed in 1941 by the Corps of Engineers, is the major flood control structure along the Santa Ana River. Its original storage volume was 275 million m^3 although this had been reduced to 244 million m^3 by 1975 as a result of sediment accumulation in the reservoir since construction. A secondary flood control reservoir built on San Antonio Creek in 1933 has a current capacity of 9.4 million m^3.

In some respects, the effect of Prado Dam on surface flow is not so pronounced as might be expected. Corps of Engineers personnel estimate that percolation losses behind the dam are small. Originally, flood flows trapped behind the dam were released as quickly as possible so that the basin would be at its maximum capacity for subsequent floodwaters. Thus, the annual volume of water flowing out of Prado Basin was not significantly affected by the existence of the dam, only the time distribution of the flow. Figure C14-3 provides an example of this flood curve attenuation.

As initially constructed Prado Dam had two large conduits that were not subject to control. These conduits carried low and medium flows past the dam with no alteration. In 1949, the first of these conduits was sealed off and in 1969 the second was closed, rendering all flow past the dam subject to operator control. The policy since 1969 has been to release inflow in carefully controlled amounts, when such strategy does not interfere with the dam's flood-control function, to allow for maximum groundwater recharge in Orange County and minimum loss (flow) to the ocean.

Comparisons of surface inflow and outflow data from Prado basin indicate that annual outflow from the basin is significantly greater than the sum of the various inflows. This is probably due to rising groundwater in the area. However, this has not been verified. In recent years, effluent from the Chino Basin Municipal Water District sewage treatment plant has contributed sizable flows to Prado basin and imported water from northern California has been transported through Prado basin via San Antonio Creek and Chino Creek for groundwater recharge in Orange County.

Prado to the Ocean

A large quantity of water, generally between 35 and 450 million m^3, leaves the Prado basin each year as a result of natural

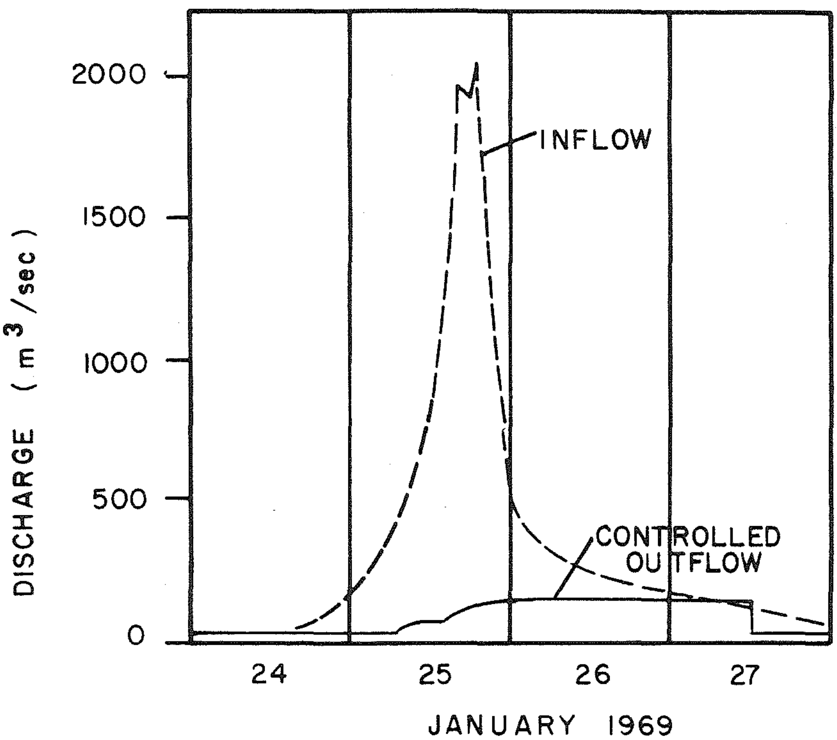

Figure C14-3 Flood Hydrograph at Prado basin during January 1969 storm.

and artificial inputs. After leaving Prado, the river flows through Santa Ana Canyon undiminished as may be expected due to the relatively thin layer of alluvium in the canyon. Below Santa Ana Canyon, in some respects the river comes to an end, although the channel continues another 30 km to the ocean. Just below the canyon there are a series of percolation basins owned by the Orange County Water District (OCWD). Enormous quantities of water, far exceeding the aggregate sum for other recharge areas in the Santa Ana River basin, are percolated at the OCWD basins. Since the construction of Prado Dam, little of the water leaving Prado gets past these basins. Only very wet years can produce an annual flow greater than 10 million m^3 at USGS station 11078000 near Santa Ana.

However, available data indicate that, during severe storm years, substantial quantities of water reach station 11078000 and flow on to the ocean. The volume of such flows is only partially affected by artificial percolation operations and the operation of Prado Dam.

Finally, it should be noted that, along the lower reach of the Santa Ana River, Carbon Canyon Creek flood control channel serves as an artificial link between the San Gabriel and Santa Ana drainages. This channel was constructed in 1961 and since that time has delivered only minor quantities of water to the Santa Ana River.

Channelization

Under natural conditions the upper (above Santa Ana Canyon) and lower Santa Ana River was free to change its course suddenly (avulsion) or migrate slowly over a broad flood plain, altering its cross sections and overflowing its banks during flood episodes. Such lateral channel movements and overbank flows are often economically damaging and dangerous, especially in urban areas.

It is to be expected then that, as with the Los Angeles and San Gabriel rivers, there have been efforts to constrain the Santa Ana. This has been done by constructing channel levees with revetment over much of the river's length. This levee/revetment channelization, however, leaves the stream free to adjust bed form and sediment transport according to local conditions.

C14.4 Gaging Stations

In view of the fact that the Santa Ana River is the largest and most heavily used river system in southern California, it is not surprising that it has also been most heavily gaged. There are currently more than 40 USGS gaging stations in operation along tributaries and the main stem of the river (see Fig. C14-2), and many other stations that, although now defunct, provide historical streamflow data. Many records date back more than 50 years and some begin around the turn of the century. Unfortunately, however, continuous streamflow records do not predate the advent of significant human controls.

Sediment discharge measurements have been made at multiple locations along the Santa Ana River by the USGS since 1967. However, as with the Los Angeles and San Gabriel rivers due to changing levels of development, these data cannot be used reliably in making estimates of either natural or actual coastal sediment deliveries during the past few decades.

C14.5 Stream Bed Characteristics

Figure C12-1 shows the planform of the Santa Ana River as it was in 1920. Based on probable channel slopes over most of the flood plain, data compiled by Leopold et al., (1964) suggest that the Santa Ana River was braided under natural conditions.

Figure C14-4 is a plot of stream-bed elevations along the main channel under present conditions. Decreasing near the coast, the river slope is approximately constant at 0.003 from 10 km to 100 km inland. The slope then quickly increases as the river approaches its headwaters area.

Bed material samples have been collected at four locations along the river. The size distributions of these samples are plotted in Fig. C14-5. Eight of the eleven samples form a rather tight pattern and indicate that along the lower Santa Ana the bed material is primarily medium sand with a geometric mean value around 0.5 mm and a geometric standard deviation of approximately 2.

C14.6 Natural Flow Characteristics

In the prior section on control facilities, a brief description was given of complications, both natural and man-made, that arise in estimating streamflows to the ocean under natural conditions during recent decades. Also, as noted, available data do not predate significant artificial diversions and controls, and thus, recent streamflows that would have been obtained under natural conditions cannot be estimated by considering characteristics during a prior period of little or no control.

The character of hypothetical recent natural streamflows to the ocean then must be inferred. With this objective, it's helpful to note the general character of surface flows under present conditions.

Figure C14-6 summarizes annual streamflow data for water year 1972. Nineteen seventy-two was a dry year in terms of rainfall and runoff and this diagram gives a general indication of surface-flow conditions throughout the basin under recent dry-year conditions. During 1972, the amount of water artificially withdrawn, or added, to the Santa Ana River is more roughly of the same order as the maximum flow in the river below Prado Dam.

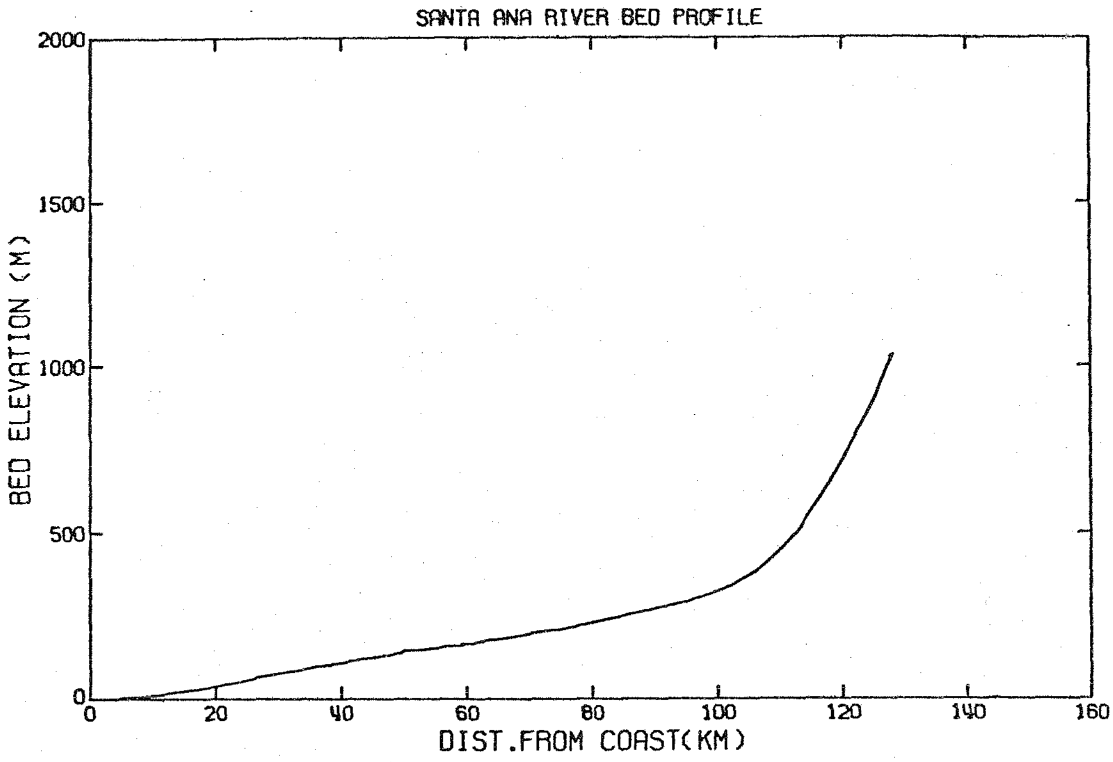

Figure C14-4: Bed Profile of the Santa Ana River under present conditions.

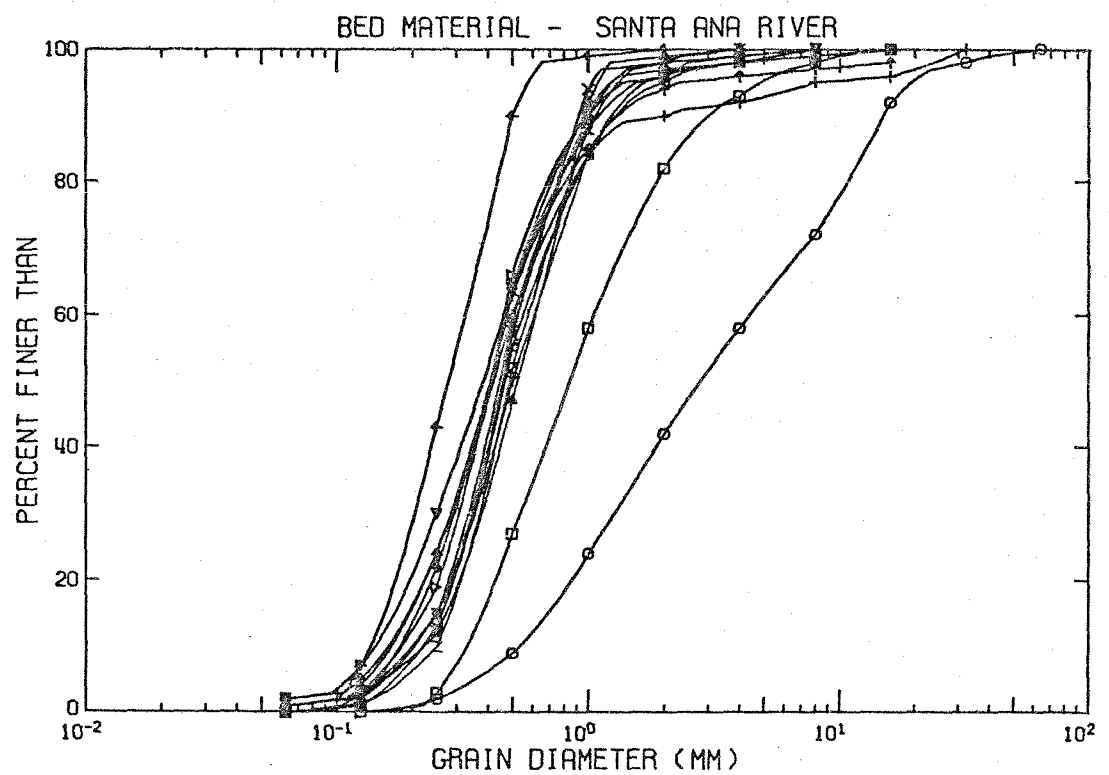

Figure C14-5: Size-Distributions of Bed Material samples collected along the lower Santa Ana River during the past 10 years.

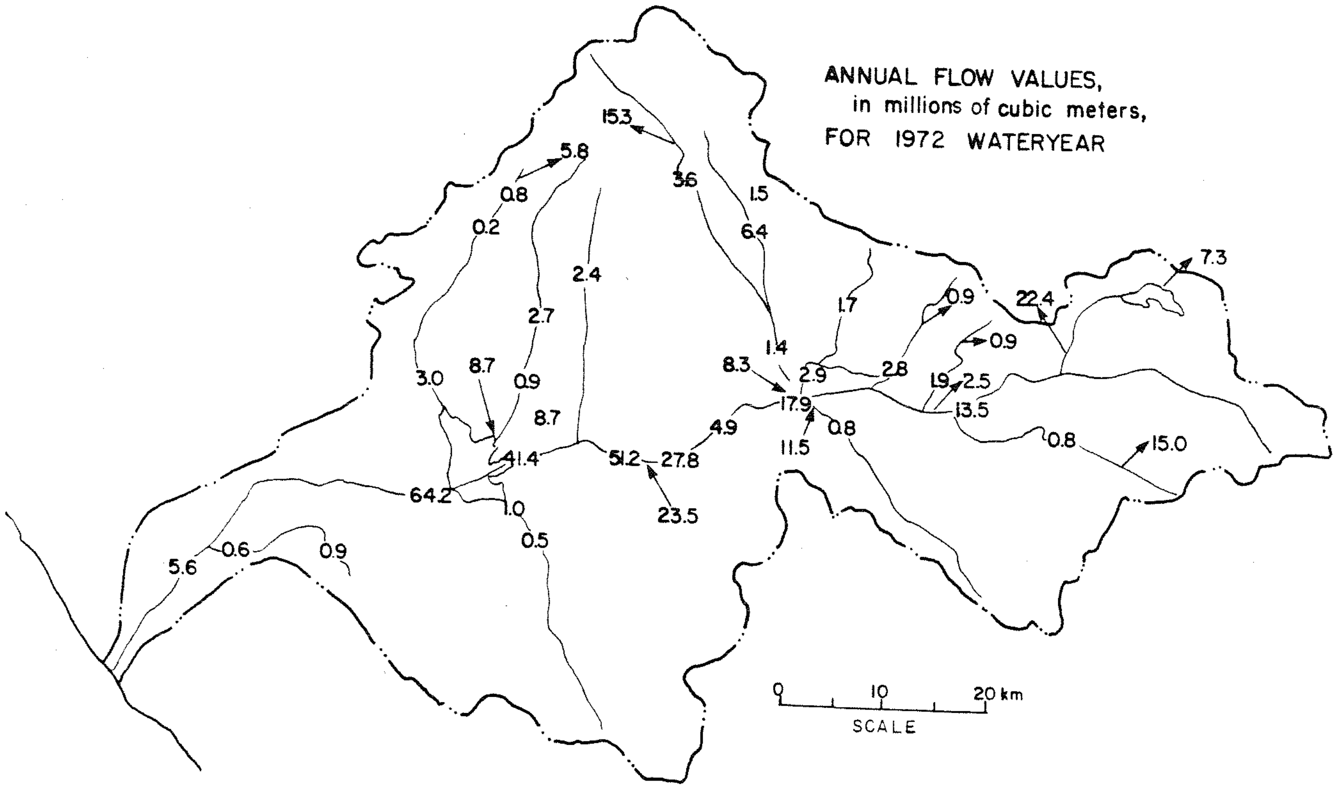

Figure C14-6: Annual Flows along the Santa Ana River during 1972 water year (Dry).

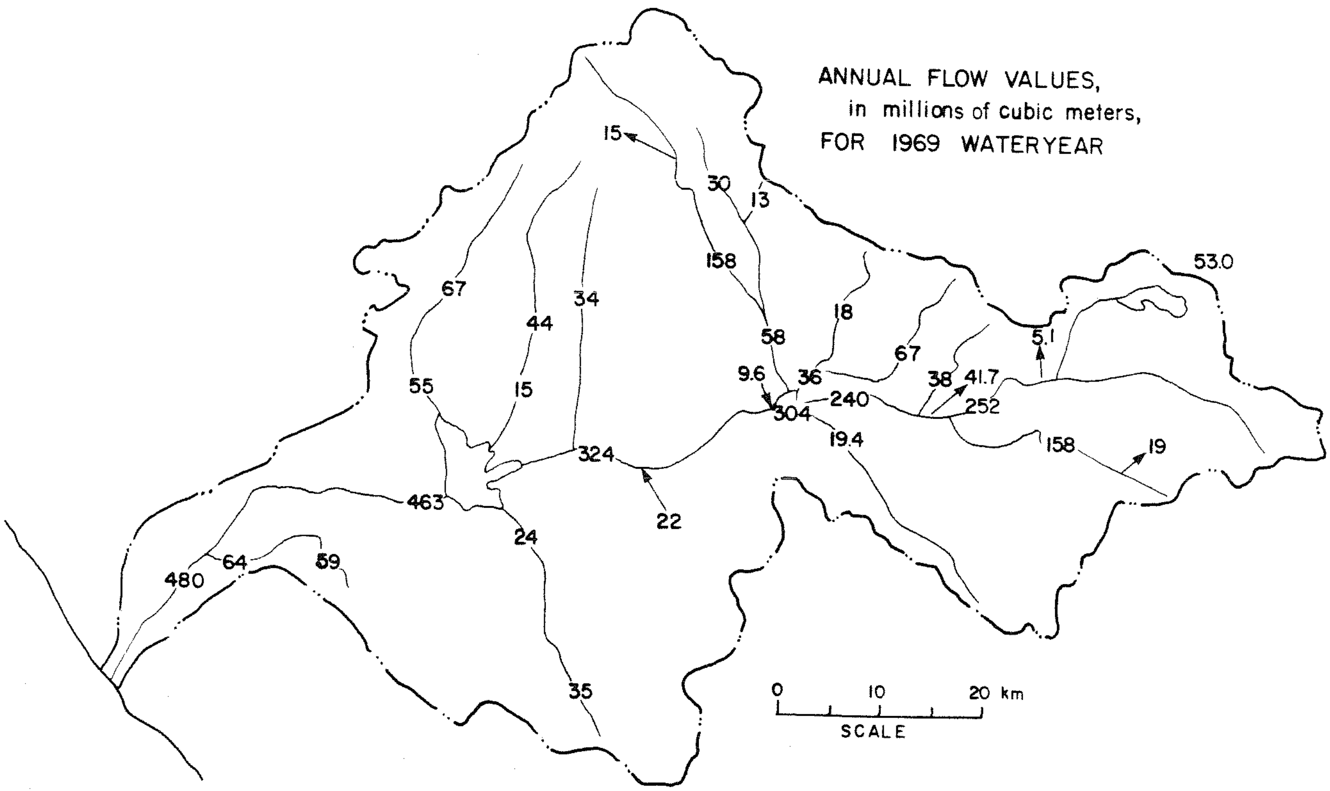

Figure C14-7: Annual Flows along the Santa Ana River during 1969 water year (Flood).

However, this maximum flow below Prado "disappears" almost entirely before reaching the ocean.

A different picture emerges when one looks at streamflow data for the year 1969 (see Fig. C14-7) which characterizes surface flow under recent flood-year conditions.

Although the diversions and artificial additions are considerable, they are secondary compared to flows along the main channel which reached a peak of 480 million m^3 near the coast.

In estimating natural flow characteristics with regard to dry and flood year conditions, a key question is: Were percolation rates along the lower reach of the Santa Ana River under natural conditions similar to those under present conditions?

The OCWD was formed in 1933 and began artificial groundwater recharge the same year. Prior to that time, there is no indication of this kind of activity along the lower Santa Ana River. However, low and intermediate streamflow data collected prior to 1933 indicate disappearances of water then in as large quantities as during recent years, apparently due to high "natural" percolations.

With regard to flood flows, in 1969 the annual flow at Santa Ana was greater than at Prado. Releases from Prado flood control reservoir amounted to 463 million m^3, and the flow measured at Santa Ana was 480 million m^3. In comparison, the severe 1938 flood produced a flow of 282 million m^3 at Prado but only 159 million m^3 at Santa Ana.

Why the relative differences in flows at the two locations during these flood years? There may be two primary reasons: First, increased urbanization in Orange County between 1938 and 1969 could be responsible for increased relative flood flow at the lower station in 1969. Second, artificially reducing peak flood discharges and restricting flow to a relatively narrow channel in 1969, rather than allowing the river to spread out over the flood plain, as in 1938, probably reduced percolation. Peak-flow from Prado Dam was limited to 164 m^3/s in 1969 whereas in 1938 the peak flow was estimated to be 2,800 m^3/s. Downstream at Santa Ana, the peak discharge during 1969 was 540 m^3/s but was 1,311 m^3/s in 1938. Whether due primarily to reduced percolation or increased urban runoff, it appears that under present conditions there is a relative increase in volumetric flow to the ocean during large storms.

Under dry-year conditions then, available data suggest that annual flows to the ocean are small compared to upstream discharges, under both natural and present conditions. Whereas with severe flood flows, there has probably been a substantial increase in runoff volume but a reduction in peak discharges with development and controls along the river.

C14-7 Annual Sediment Deliveries to the Coast

As elsewhere in southern California, most inland sediment movements in the Santa Ana River basin are driven by surface streamflow. In the absence of adequate streamflow (and sediment discharge) data under natural conditions, a primary attempt to identify differences between natural and actual sediment deliveries to the coast might first examine probable effects of the dominant control structure along the river -- Prado Dam.

Periodic surveys of sediment accumulation behind Prado Dam provide data which can be used to estimate in part the effect of this significant control on sediment delivery to the ocean.

Storage Volumes in Prado Reservoir*

Original storage volume (1941)	275.1 million m^3
Storage Volume in 1960	267.7 million m^3
Storage Volume in 1975	244.2 million m^3

*Los Angeles District, Corps of Engineers

The above data indicate an average rate of reservoir deposition from 1941 to 1975 of 0.91 million m^3 per year. From 1941 to 1960, a period with no severe storm years in terms of sediment production or flooding, the average annual sediment yield was 0.39 million m^3. At this rate, the expected accumulation behind the dam for the period 1961-1975 would be 5.8 million m^3. The actual accumulation, however, was 23.5 million m^3. The difference of 17.7 million m^3 approximates the contribution of the severe storm year 1969, inasmuch as other years during this 15-year period were more or less average.

Based on sediment-discharge measurements at station 11078000 near Santa Ana, the USGS has estimated the total sediment transport during 1969 to be 7.65 million m^3. About 3.0 million m^3 of this material, primarily the sand in transit, was deposited either in the channel near the ocean or at the river's mouth with the remainder apparently lost to deeper offshore ocean areas.

A comparison of these figures with the estimated 17.7 million m^3 retained behind Prado Dam suggests that the effect of the dam in reducing sediment delivery to the shoreline during this severe storm year may have been very large. By retaining sediment from the upper basin, Prado prevented this material from reaching the lower reach and perhaps the shoreline. Also, with reduced peak discharges the stormflow released from Prado had a reduced ability to pick up and transport sediment along the lower reach and, thus, channel erosion was not nearly as severe as it might have been with a natural hydrograph.

Would sediments trapped in Prado basin during 1969 have been delivered to the shoreline, and how much downstream channel scour would have taken place under natural discharge conditions? Historical data help answer these questions. A short time prior to the severe flood of 1938, the Corps of Engineers and the Orange

County Flood Control District surveyed 30 channel cross-sections between the coast (the Pacific Coast Highway) and a location near the present site of Prado Dam. Following the flood, these cross-sections were resurveyed, and the two sets of data were analyzed to determine scour and fill at each of these sections (Troxell, 1942). At 28 of the 30 cross-sections there was net degradation during the flood, and only two of the cross-sections indicated net aggradation.

Using straight-line interpolation between the cross-sections, estimates of net scour along the entire lower reach have been obtained. These estimates indicate a net scour along the channel of more than 9 million m^3 with most of the scour occurring near the mouth of the canyon. These data suggest that severe natural flood flows are erosive rather than depositional along the lower reach. This same flood channel-scour phenomenon has been observed on upland catchments as explained in Report 17-B. On upland catchments during dry and moderate years, aggradation seems to take place in drainage channels, then with a severe storm, this material is removed and there is channel erosion. In Fig. C14-8, changes in local channel elevation between 1919 and 1938 are plotted for a stream-gaging station on the Santa Ana River near the present site of Prado Dam. This plot indicates that during flood flows, there is scour and bed elevations which are significantly reduced, whereas during intervening years the channel aggrades.

Figure C14-8 also indicates net channel degradation over this 19-year period. This may be the result of reduced low flows due to artificial controls during moderate years and thus reduced natural resupply of channel material. Or, it may be part of a longer term cyclic variation or permenant river adjustment.

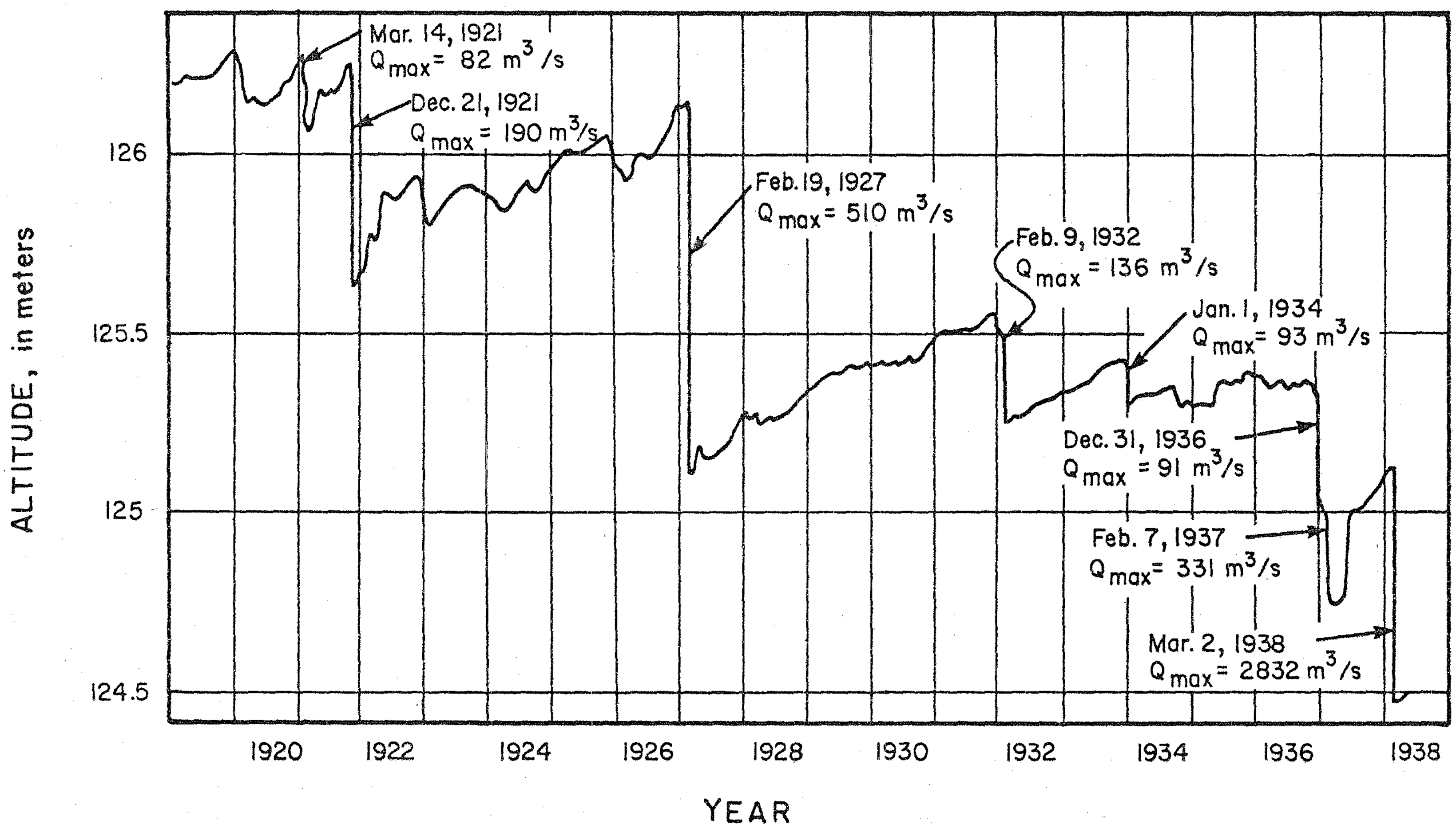

Figure C14-8: Change in zero-discharge elevation for 19-year period at gaging Station near present site of Prado Dam (Troxell, 1942).

These results suggest that in 1969 without Prado Dam, not only would sediment trapped behind the dam have been delivered to the shoreline but also a fairly large amount of material eroded from the natural channel along the lower reach. If it is assumed that the floods of 1938 and 1969 were roughly equivalent in terms of sediment movement, then in 1969 if natural conditions had obtained, rather than a coastal sediment delivery of 7.65 million m^3 (3.0 million m^3 of sand), it may have been as much as 25-35 million m^3 with perhaps 10-15 million m^3 (40%) of sand-sized material.

Using this estimate and neglecting all lesser coastal sediment delivery events, a conservative estimate of average annual sand delivery to the coast between 1940 and 1970 would be 330,000-500,000 m^3, under natural conditions.

Kroll (1975), using streamflow data and sediment discharge data at USGS station 11078000 (where sediment measurements began in 1967) and assuming a stable relationship between sediment discharge and water discharge, has estimated that, except for 1969, the actual average annual sediment discharge at this station near the coast during the period 1941-1971, was 0.10 million m^3 per year. Assuming 40 percent of this material is sand, and prorating the measured 1969 coastal sand delivery over the 30-year period would give an estimate of 140,000 m^3/year coastal sand delivery under actual conditions.

These estimates suggest that during recent decades coastal sand deliveries by the Santa Ana River have been reduced 190,000-360,000 m^3 (60 to 70 percent).

C15 Extensively Developed Basin - Summary and Conclusions

The contiguous Los Angeles, San Gabriel, and Santa Ana river basins form the primary drainage network for one-fourth of the coastal drainage in southern California.

There is general similarity among the three basins in their physiography and geology. Each river heads in steep rugged catchments formed in granitic-metamorphic mountains which rise to thousands of meters. The upland catchments terminate rather distinctly in alluviated inland valleys. Under natural conditions, low and moderate streamflows disappeared in these valleys, along reaches of high percolation. Then further downstream the subsurface water reappeared in at least two of the three rivers. Each of the rivers leaves its inland valley through a natural topographic constriction and then flows across coastal plains for several kilometers to the ocean.

Annual rainfall on these drainages varies from 15 to 25 cm on coastal plains and to 100 to 125 cm in the mountains, with significant storm activity generally affecting all three basins.

On all three rivers there have been significant natural channel migrations, and large avulsive changes along the lower reaches during the past 200 years. The more severe changes were brought about by severe flood flows.

After the turn of the last century large-scale human developments began within the extended basin forming the three drainages. This development period, which had its strongest focus in and around the City of Los Angeles, began with many smaller settlements throughout the area. Today virtually all of the low-lying areas in the Los Angeles River drainage and most of the low-lying areas in the San Gabriel drainage are urbanized.

With development additional needs for water arose, and also concern for protection against flood flows common to the area. These needs and concerns have led to near ultimate systems of flood control including large and small debris and flood entrapment basins, and channelization, as well as numerous water conservation reservoirs, and groundwater recharge facilities.

The developments -- urbanization, flood control, water conservation, groundwater recharge and pumping, and surface flow diversion -- have effected essentially artificial streamflows and sediment discharge conditions along the lower reach of each of the three rivers. Available data and information indicate that these developments have produced sharp reductions in sediment delivery to the lower reaches and the coast.

Under natural conditions, low and moderate annual flows brought sediments down from upland hillslopes and probably deposited these sediments along river channels, and in near-shore lagoon/bay/marsh areas where the rivers terminated.

Large natural flood flows delivered huge quantities of sand, silt, and clay-sized sediments to the shoreline, building large, sandy deltas near the mouth in just a few hours or days. These materials were derived during the storm, from hillslope erosion and channel scour. Under natural conditions, storms like those of 1938 and 1969 probably delivered a total of 15 to 20 million m^3 of sand to the coast from the three drainages. With the natural migration and periodic avulsion of channel outlets to the ocean, this material was delivered to beach areas over an 80-km reach of shoreline from Santa Monica to Newport Bay. However, the major portion of the streamborne sediments were delivered to the southeastern reach of shoreline between the Palos Verdes Peninsula and Newport Bay. Estimates (Table C15-1) based on available information suggest that under natural conditions these three rivers delivered an average of at least one million m^3/yr of sand.

TABLE C15-1: Estimated Sand Deliveries under Natural Versus Present Conditions for Extensively Developed Basins

River	Area (km^2)	Estimated Average Annual Sand Discharge: Natural Conditions (m^3/yr)	Estimated Average Annual Sand Discharge: Present Conditions (m^3/yr)
Los Angeles River	2,155	600,000	200,000*
San Gabriel River	1,663		
Santa Ana River	4,406	330,000 - 500,000	140,000

*Estimated to be 1/3 of natural rate (see pp. C245-246).

Under present conditions, with channelization along the lower reaches, shoreline sand delivery is probably not as intermittent as under natural conditions. But average annual coastal delivery of sand-sized material has been reduced to 0.3 to 0.4 million m^3.

Present conditions (channelization) also fix the location of river outlets, preventing a natural variable distribution of streamborne sediments along the shoreline. Considering the historical migrations of the rivers, artificial stabilization may be as severe in terms of shoreline stability as the probable reductions in sand delivery.

The data base on flood flows and sediment transport has mostly been taken concurrently with or after man's extensive developments and modifications of these three rivers and their flood plains. Furthermore, systematic sediment discharge measurements near the mouths of the Los Angeles and San Gabriel Rivers were begun only in 1976. Therefore, the annual sand discharge values given in Table 15-1 are subject to large errors, and must be considered only as good order-of-magnitude estimates.

ADDENDA

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C17 Explanation of Gaging Station Tables

Gaging station tables in Sections C3 through C10 are augmentations of tables taken directly from California Department of Water Resources (DWR, 1978) Bulletin No. 230-78. The tables have been augmented by the addition of the following two columns:

MAP CODE: Each station is marked on an accompanying drainage basin map by a map code consisting of either a letter or a letter and a numeral. An asterisk in the map code column denotes stations which have record lengths of 15 years or more (these stations are indicated on the map by larger triangles).

CLASS: The class of a record is the type of record collected at the station. The source for this information is DWR (1971) Bulletin No. 157, and the code therein has been adopted here. For newer stations USGS, DWR, and county sources have been consulted. The DWR (1971, p. 25) code is found on the following page.

The remaining columns are the same as those given by the DWR (1978). The explanation of column headings given by the DWR (1978, pp. 13-21) is reproduced here.

Class of Record Code

CODE	CLASS OF RECORD
1	Daily discharge, continuous
1X	Fragmentary periods of daily discharge
1R	Daily discharge, computed from operation records
2	Daily discharge, seasonal
2X	Daily discharge, synthetically determined
3	High water season, daily discharge
3X	Maximum discharge, crest stage program (indirects)
3R	Maximum discharge, and base flow small streams program
4	Low water season, daily discharge
4X	Base flow measurements only
5	Monthly or yearly flow or runoff only
5X	Monthly or yearly flow or runoff, fragmentary
5R	Monthly or yearly flow, synthetically determined
6	Daily stage, river station, continuous
6X	Daily stage, river station, fragmentary
6R	Maximum stage, river station (no discharge available)
7	Daily stage, lake or reservoir
7X	Fragmentary periods of daily stage, lake or reservoir
8	Daily contents, lake or reservoir (implies stage also)
8X	Fragmentary periods of daily contents, lake or reservoir
8R	Month and record of contents, lake or reservoir
9	Periodic discharge measurements (not otherwise coded)
9X	Daily discharge, preceded or followed by occasional discharge measurement
7R	Daily stage on Bay System

EXPLANATION OF COLUMN HEADINGS

SURFACE WATER MEASUREMENT

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	YEAR END	YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

The DWR number assigned to a surface water measurement station consists of six characters - a letter and five digits of the form A1-2345. While the last four characters define a station location in upstream order on a particular stream, the first two characters have an areal designation orientation derived from the following table.

A – Sacramento River Area

- 0 – Sacramento Valley Floor
- 1 – Pit River
- 2 – Shasta Lake
- 3 – Sacramento Valley Westside
- 4 – Sacramento Valley Northeast
- 5 – Feather River
- 6 – Yuba-Bear Rivers
- 7 – American River
- 8 – Cache Creek
- 9 – Putah Creek

B – San Joaquin River Area

- 0 – San Joaquin Valley Floor
- 1 – Cosumnes River
- 2 – Mokelumne-Calaveras River
- 3 – Stanislaus River
- 4 – Tuolumne River
- 5 – Merced River
- 6 – Fresno-Chowchilla River
- 7 – San Joaquin River
- 8 – San Joaquin Valley Westside
- 9 – Sacramento-San Joaquin

C – Tulare Lake Area

- 0 – Tulare Lake Valley Floor
- 1 – Kings River
- 2 – Kaweah River
- 3 – Tule River
- 4 – Green Horn Mountains
- 5 – Kern River
- 6 – Tehachapi Mountains
- 7 – Tulare Lake Basin Westside

D – Central Coastal Area

- 0 – Santa Cruz
- 1 – Pajaro-San Benito Rivers
- 2 – Lower Salinas River
- 3 – Upper Salinas River
- 4 – Monterey Coast
- 5 – San Luis Obispo Coast
- 6 – Santa Maria-Cuyama
- 7 – Carrizo Plain
- 8 – Santa Ynez River
- 9 – Santa Barbara Coast

E – San Francisco Bay Area

- 0 – San Francisco Bay
- 1 – Coast-Marin
- 2 – Marin-Sonoma
- 3 – Napa-Solano
- 4 – East Bay
- 5 – Alameda Creek
- 6 – Santa Clara Valley
- 7 – Bayside-San Mateo
- 8 – Coast-San Mateo

F – North Coastal Area

- 0 – Smith River
- 1 – Lost River-Butte Valley
- 2 – Shasta-Scott Valleys
- 3 – Klamath River
- 4 – Trinity River
- 5 – Mad River
- 6 – Eel River
- 7 – Mattole River
- 8 – Mendocino
- 9 – Russian River

G – North Lahontan Area

- 1 – Surprise Valley
- 2 – Madeline Plains
- 3 – Eagle Lake
- 4 – Susan River
- 5 – Smoke River
- 6 – Herlong
- 7 – Truckee River
- 8 – Carson River
- 9 – Walker River

V – South Lahontan Area

- 0 – Mono Lake
- 1 – Adobe Valley
- 2 – Owens River
- 3 – Cottonwood Creek
- 4 – Deep Springs
- 5 – Amargosa River
- 6 – Ivanpah
- 7 – Searles Lake
- 8 – Antelope Valley
- 9 – Mojave River

W – Colorado River Area

- 1 – Mojave Desert
- 2 – Needles-Colorado River
- 3 – Whitewater River
- 4 – Carrizo Creek
- 5 – West Salton Sea
- 6 – East Salton Sea
- 7 – Blythe-Yuma-Colorado River
- 8 – Coyote Wash
- 9 – Imperial Irrigation District

X – San Diego Area

- 1 – San Joaquin Creek
- 2 – Santa Margarita River
- 3 – San Luis Rey River
- 4 – San Dieguito River
- 5 – San Diego River
- 6 – Sweetwater River
- 7 – Otay River
- 8 – Tia Juana River

Y – Santa Ana Area

- 1 – Santa Ana River below Narrows
- 2 – Chino Creek
- 3 – Lytle-Cajon Creeks
- 4 – Warm City Creeks
- 5 – Santa Ana Headwaters
- 6 – Santa Ana River above Narrows
- 7 – San Timoteo Creek
- 8 – Temescal Wash-Elsinore
- 9 – San Jacinto River

Z – Los Angeles Area

- 1 – Ventura River
- 2 – Lower Santa Clara River
- 3 – Upper Santa Clara River
- 4 – Calleguas-Conejo Creeks
- 5 – Ventura Los Angeles Coastal
- 6 – Los Angeles River
- 7 – San Gabriel River above Narrow
- 8 – San Gabriel River below Narrow

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	YEAR END	YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This is an eight-digit number that identifies the station under the coding system of the U.S. Geological Survey. [Editors note: the DWR gives this number in the form 11-0135.00, while recent USGS publications give the same number as 11013500. Therefore, while the former form is given in the tables, the latter is used in the text.]

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°-MIN'-SEC"	LONGITUDE DEG°-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD			QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
								YEAR BEGIN	YEAR END	YEARS MISSING				

This is the name assigned or adopted by the Department of Water Resources that provides general information about the stream and its location in relation to the nearest prominent landmark. It may differ from the name assigned by other agencies involved with the station. These entries have been abbreviated to fit the 33-character space available.

Station names are divided into three units, set off by commas, which identify the stream, branch of the stream, and the landmark near the station's location on the stream. For example, <u>OSBORN C, SF, A LEANING TREE RD</u> identifies the station on the south fork of Osborn Creek at Leaning Tree Road.

Standard abbreviations used throughout...[gaging station tables are]:

A	at	HG	headgate	PP	powerplant
AB	above	HQ	headquarters	PT	point
AC	acre	HW	headworks	PU	pump
ALT	alternate	HWY (HY)	highways	PUPL	pumping plant
AQU	aqueduct	HI	high	PWR (PR)	power
AVE (AV)	avenue	ID	irrigation district	R	river
+	and	IF	inflow	RASTA	ranger station
B	branch	INT (INTER)	international	R-D	reclamation district
BAS	basin	INL	inlet	RD	road
BDY (BNDRY)	boundary	IRR	irrigation	RES	reservoir
BL	below	IT	intake	RESER	reservation
BLVD (BLD)(BV)	boulevard	ISL	island	RH	ranch
BP	bypass	JCT	junction	RNG	range
BR	bridge	L	little	RNGR	ranger
C	creek	LA (LN)	lane	RR	railroad
CA	canal	LA AQU	Los Angeles aqueduct	S	south
CF	cutoff	LD	land	SB	south branch
CG	campground	LDG	landing	SCH	school
CH	channel	LI	line	SF	south fork
CN	canyon	LK	lake	SJ	San Joaquin
CO	company	LO	lower	SLU	slough
COND (CD)	conduit	M	middle	SO	southern
COU	county	MB	middle branch	SP	spill
CP	camp	MDW (MD)	meadow(s)	SPDG	spreading grounds
CT	court	MF	middle fork	SPLWY (SPWY)	spillway
CTY	city	MI	mile	SPR	spring(s)
D	ditch	MN	main	ST (STS)	street(s)
DD	diversion ditch	MO	mouth	STA	station
DEB	debris	MT	mountain	STO	storm
DI	dike	N	north	STODR	storm drain
DIV	diversion	NB	north branch	TR	tailrace
DM	dam	NF	north fork	TRIB	tributary
DR	drain	NLY	northerly	TU	tunnel
DRI	drive	NO	number	U	university
DS	downstream	NOR	northern	UP	upper
DMS	damsite	NR	near	US	upstream
E	east	OFL	outflow	VLY	valley
EB	east branch	OL	outlet	VET-MET	venture meter
EF	east fork	OPP	opposite	W	west
F	fork	P	pit	WAS (WA)	wash
FD	field	PD	pond	WB	west branch
FL	flume	PERC	percolation	WD	water district
FOBY	forebay	PH	powerhouse	WF	west fork
FY	ferry	PI	pipe	WR	weir
GT	gate	PK	park	WT	water
GTS	gates	PL	pipeline	WY	wasteway
HD	head	PLT	plant	XING	crossing

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	YEAR END	YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This is the latitude and longitude of the station in degrees, minutes, and seconds.

(Normally these coordinates would locate the station within about 50 feet. However, most of the stations listed here were converted from previous least values of tenths of minutes, and, therefore, would only locate the station within about 500 feet. This latter circumstance may be surmised if the seconds of both latitude and longitude are divisible by six.)

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	YEAR END	YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This a three-letter abbreviation that identifies the county in which the station is located.

Code	County
ALA	Alameda
ALP	Alpine
AMA	Amador
BUT	Butte
CAL	Calaveras
COL	Colusa
CCA	Contra Costa
DNT	Del Norte
ELD	El Dorado
FRE	Fresno
GLE	Glenn
HUM	Humboldt
IMP	Imperial
INY	Inyo
KRN	Kern
KNG	King
LAK	Lake
LAS	Lassen
LAX	Los Angeles
MAD	Madera
MRN	Marin
MPA	Mariposa
MEN	Mendocino
MER	Merced
MOD	Modoc
MNO	Mono
MNT	Monterey
NAP	Napa
NEV	Nevada
ORA	Orange
PLA	Placer
PLU	Plumas
RIV	Riverside

Code	County
SAC	Sacramento
SBT	San Benito
SBD	San Bernardino
SDG	San Diego
SFO	San Francisco
SJQ	San Joaquin
SLO	San Luis Obispo
SMT	San Mateo
SBA	Santa Barbara
SCL	Santa Clara
SCR	Santa Cruz
SHA	Shasta
SIE	Sierra
SIS	Siskiyou
SOL	Solano
SON	Sonoma
STA	Stanislaus
SUT	Sutter
TEH	Tehama
TRI	Trinity
TUL	Tulare
TUO	Tuolumne
VEN	Ventura
YOL	Yolo
YUB	Yuba
ORE	Oregon (State)
NVS	Nevada (State)
ARZ	Arizona (State)
MEX	Mexico
POS	Pacific Offshore

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This is a four-digit number, assigned by the Department of Water Resources, that identifies the agency currently operating the station, or the agency that last operated it, if it is subsequently discontinued.

Code	Agency
1101	Los Angeles County Flood Control District
1200	Los Angeles, City, Department of Water and Power
1400	Whitewater Mutual Water Company
1401	San Diego County
1434	Yuba County Water Agency
1468	U. S. Coast and Geodetic Survey
1482	San Benito County Flood Control and Water Conservation District
1492	Nevada Irrigation District
1839	U. S. Energy, Research and Development Administration
1872	Mosquito District Municipal Water Company
1922	Pacheco Pass Water District
2256	Tahoe Regional Planning Agency
2332	Casitas Municipal Water District
2342	Butte Valley Irrigation District
2390	Tule Irrigation District
2400	Santa Clara Valley Water District
2484	La Canada Irrigation District
2487	Kings River Water Association
2492	Tuolumne County Water District No. 2
2581	Modoc County Irrigation District
2583	Bay Cities Water Company
2624	Siskiyou County
2625	Siskiyou County Flood Control and Water Conservation District
2668	Placer County Water Agency
2806	Oroville-Wyandotte Irrigation District
2820	Walker River Irrigation District
2823	South Santa Clara Valley Water Conservation District
2863	Tulare County
2907	Sonoma County Flood Control District
2908	Sonoma County Water Agency
2917	San Joaquin Canal Company
2925	U. S. Soil Conservation Service
2980	Western Municipal Water District
3207	California Department of Transportation
3210	Pasadena, City
3366	Happy Valley Irrigation District (dissolved 1925)
3400	San Bernardino Valley Water Conservation District
3774	Santa Barbara, City
3901	Santa Ynez River Water Conservation District
3914	Lake Hemet Municipal Water District
3922	U. S. National Weather Service
3964	Berrenda Mesa Water District
3983	Napa County Flood Control and Water Conservation District
3989	Arrowhead Corporation
4202	Sacramento Municipal Utility District
4355	Palmdale Water District (ID)
4372	Palo Verde Irrigation District
4382	Paradise Irrigation District
4405	Vista Irrigation District
4412	The Metropolitan Water District of Southern California
4417	Orange County Water District
4700	Palm Springs Water Company
4706	Fontana Union Water Company
4740	Southern California Edison Company
4748	San Antonio Water Company
4892	Lake County Flood Control and Water Conservation District
4926	San Mateo County Flood Control District
5000	U. S. Geological Survey
5001	U. S. Bureau of Reclamation
5002	U. S. Department of Army
5003	U. S. Department of Navy
5005	U. S. Forest Service
5009	U. S. Bureau of Sport Fisheries and Wildlife
5015	U. S. International Boundary and Water Commission
5050	California Department of Water Resources
5073	California Department of Fish and Game
5075	University of California, Davis
5100	Alameda County Flood Control and Water Conservation District
5101	San Bernardino County Flood Control District
5102	Orange County Environmental Management Agency
5103	Riverside County Flood Control and Water Conservation District
5107	Placer County
5108	Sacramento County
5115	Monterey County Flood Control and Water Conservation District
5117	San Luis Obispo County Flood Control and Water Conservation District
5121	Ventura County Flood Control District
5133	Kern County Water Agency
5135	Coachella Valley County Water District
5204	San Francisco, City and County
5229	San Diego, City
5400	Helix Water District (ID)
5401	Alameda County Water District
5404	Santa Maria Valley Water Conservation District

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

CONTINUED

Code	Agency
5409	Imperial Irrigation District
5411	United Water Conservation District
5412	San Bernardino Valley Municipal Water District
5415	South Sutter Water District
5515	Central California Irrigation District
5518	South San Joaquin Irrigation District
5520	Oakdale Irrigation District
5521	Modesto Irrigation District
5524	Turlock Irrigation District
5525	Merced Irrigation District
5527	El Nido Irrigation District
5530	Madera Irrigation District
5604	Tulare Irrigation District
5611	Sausalito Irrigation District
5613	Delano-Earlimart Irrigation District
5619	Terra Bella Irrigation District
5630	Tulare Lake Basin Water Storage District
5631	Fresno Irrigation District
5640	Buena Vista Water Storage District
5650	California State Water Resources Control Board
5694	Mexico, Ministry of Hydraulic Resources, Govt.
5703	California-American Water Company (Calif. W&T Co.)
5706	Pacific Gas and Electric Company
5711	Escondido Mutual Water Company
5712	Dudley, Miller, and Lux
5714	Etiwanda Water Company
5717	Temescal Water Company
5760	Kern County Land Company
5999	Unknown Agency
6229	Bear Valley Mutual Water Company
6235	Contra Costa County Flood Control and Water Conservation District
6236	Colony Holding Corporation
6250	Stone and Webster Engineering Corporation
6308	Sierra Pacific Power Company
6361	Santa Barbara County Flood Control and Water Conservation District
6577	Truckee-Carson Irrigation District
7700	Georgetown Divide Public Utility District
7707	Marin, North, County Water District
7715	Desert Water Agency
7736	Marin County
7747	Marin Municipal Water District
7778	Duryea, Hael, and Gilman (San Francisco engineering firm, now defunct)
8043	Montecito County Water District
8085	Woodbridge Irrigation District
8090	Ventura County
8093	Yolo County Flood Control and Water Conservation District
8132	Montague Water Conservation
8185	Kaweah and St. Johns Water Association
8201	East Bay Municipal Utility District
8212	Long Valley Irrigation District
8904	U. S. Bureau of Land Management
9009	San Jose Water Works
9018	San Rafael, City
9040	Santa Cruz County Flood Control and Water Conservation District
9067	Modoc County
9200	U. S. National Park Service
9446	San Diego County Flood Control and Water Conservation District

[Editors note: Two stations in Mexico, not given by the DWR have been added to Table C10-3. The operating agency is given as IBWC, representing the International Boundary and Water Commission, United States and Mexico.]

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD			QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
								YEAR BEGIN	YEAR END	YEARS MISSING				

This is a two-letter abbreviation that identifies the Department of Water Resources' District in which the station is located or other DWR subdivision that operates the station.

Code	DWR Organization
ND	Northern District
CD	Central District
SJ	San Joaquin District
SD	Southern District
OM	Division of Operations and Maintenance (Department-wide, headquartered in Sacramento)

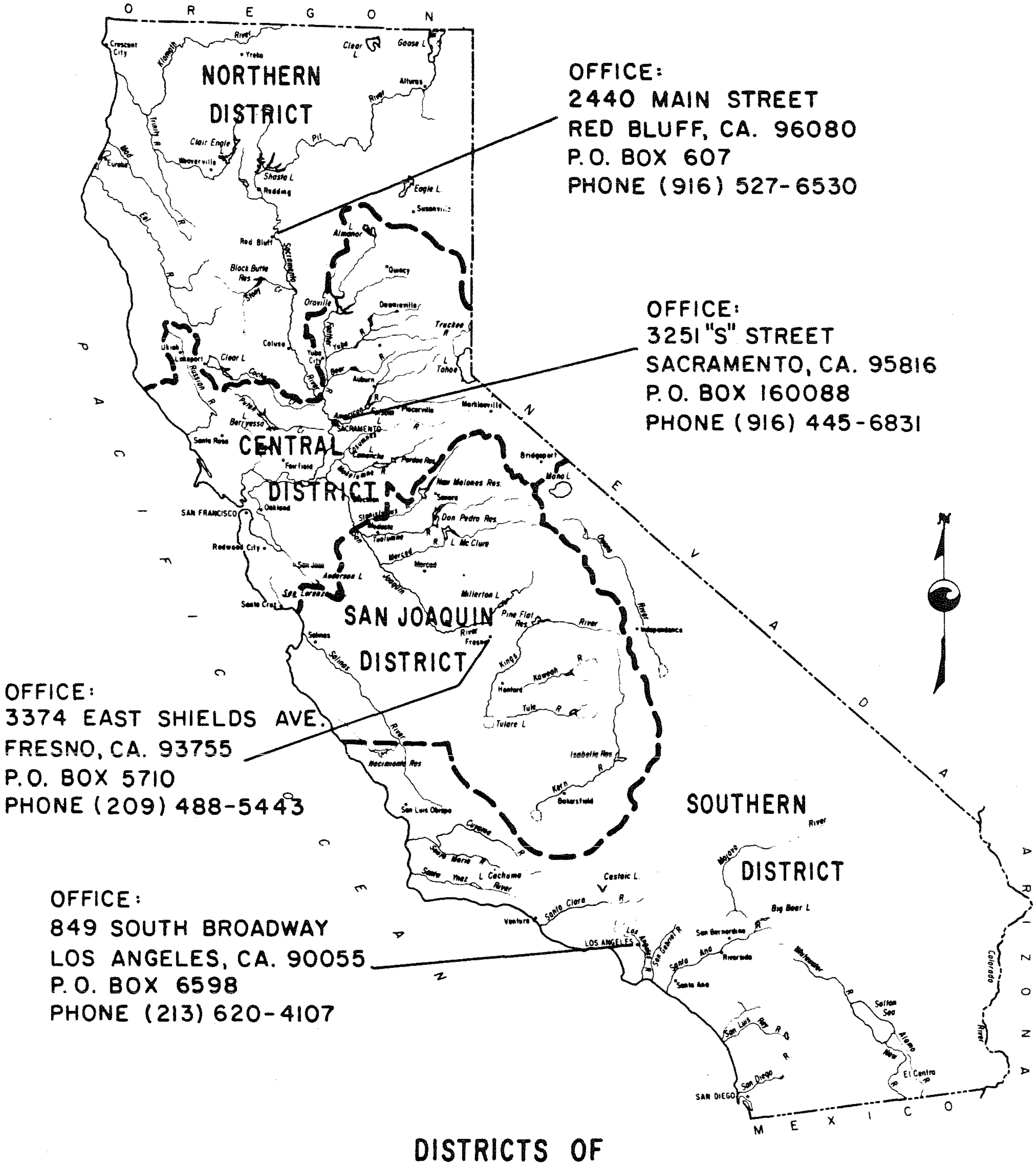
DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD			QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
								YEAR BEGIN	YEAR END	YEARS MISSING				

The dates in these columns indicate the periods of time during which the station has been in operation.

Year Begin - This is the year the station was first installed.

Year End - This is the year in which the station was discontinued. It is the latest date, if the station has been discontinued more than once. The column is blank if the station is still in operation.

Years Missing - This is a two-digit number that denotes the total number of years of missing record since the station was first installed. If the station was discontinued and restablished more than once, the missing record would be the total number of years that the station was inactive.



DISTRICTS OF
THE DEPARTMENT OF WATER RESOURCES

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°-MIN'-SEC"	LONGITUDE DEG°-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This code indicates DWR's subjective estimate of the degree of accuracy of the daily flow records, giving consideration to all parameters -- equipment, method, frequency of measurement, etc.

Code	Definition
E - Excellent	Error less than five percent
G - Good	Error less than ten percent
F - Fair	Error less than 15 percent
P - Poor	Error greater than 15 percent
U - Unknown	Relative accuracy unknown

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°-MIN'-SEC"	LONGITUDE DEG°-MIN'-SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD YEAR BEGIN	RECORD YEAR END	RECORD YEARS MISSING	QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE

This is the size of the drainage basin in square kilometres in which the station is situated. It begins at the station and proceeds upstream. The dimension is rounded off to three significant figures but not less than the nearest hundredth square kilometre. For example:

0.76 square kilometre
7.65 square kilometres
76.5 square kilometres
765 square kilometres
7,650 square kilometres

(Square miles = .0386 x square kilometres.)

SURFACE WATER MEASUREMENT STATION INDEX

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD			QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
								YEAR BEGIN	YEAR END	YEARS MISSING				

This is the altitude of the station above mean sea level in metres. (Feet = 3.28 x metres.)

DWR STATION NUMBER	USGS STATION NUMBER	STATION NAME	LATITUDE DEG°.MIN'.SEC"	LONGITUDE DEG°.MIN'.SEC"	COUNTY	OPERATING AGENCY	DWR DISTRICT	RECORD			QUALITY	DRAINAGE AREA Sq. Kilometres	ALTITUDE Metres	SOURCE
								YEAR BEGIN	YEAR END	YEARS MISSING				

This is a five-digit space reserved for the symbols that indicate the sources from which data for the station might be acquired. If various periods of record are available from more than one source, these sources are identified chronologically from left (oldest period) to right (most recent period). The general class of source - Federal, State or Local - can usually be more specifically identified by referring to the operating and/or cooperating agency listed on pages 16 and 17. Use of symbols denoting "Federal", "State", and/or "Local" also implies publication of the data, whereas use of the symbol denoting "Not Published" (usually referring to a local agency) directs the user to that agency to obtain the data.

Code	Definition
F	Federal
S	State
L	Local
N	Not Published

C18 Notes on Sediment Predictions and Curve Fitting

Two fundamentally different types of rating curves have been used in this report. For each type, a different curve-fitting technique has been applied. This section contains a discussion of each type of rating curve and the appropriate curve fitting technique. Also included in this section is a discussion of the nonlinear curve fitting technique that has been applied to other hyrologic data.

C18.1 Instantaneous Rating Curves

One of the simplest and most often used relationships for sediment transport can be represented by

$$\hat{Q}_s = aQ^b \tag{C18-1}$$

where $\hat{Q}_s$ is the predicted sediment transport rate, Q is the water discharge, and a and b are constants. Here, the constants have been determined by taking logarithms of both sides of Eq. C18-1, and performing a simple linear regression, as described briefly below.

Errors in the data and the approximate nature of the model, cause some differences to exist between predicted values, $\hat{Q}_{si}$, and observed values, Q_{si}, where the subscript i represents the i^{th} observation. If the errors are assumed to be relative rather than absolute, then the observed and predicted values can be related by

$$Q_{si} = 10^{\varepsilon_i}\hat{Q}_{si} \tag{C18-2}$$

where ε_i is an error term. This means that as ε_i approaches zero, $\hat{Q}_{si}$ approaches Q_{si}, and if $\varepsilon_i = 1$, $\hat{Q}_{si}$ is ten times too low, and if $\varepsilon_i = -1$, $\hat{Q}_{si}$ is ten times too high.

Combining Eqs. C18-1 and C18-2 gives

$$Q_{si} = 10^{\varepsilon_i} a Q_i^{\,b} \tag{C18-3}$$

Taking logarithms of both sides of Eq. C18-3 and using the transformation $G_{si} = \log Q_{si}$, $G_i = \log Q_i$, $a' = \log a$, $b' = b$, gives

$$G_{si} = b'G_i + a' + \varepsilon_i \tag{C18-4}$$

The constants a' and b' can now be solved by ordinary linear regression techniques (see, for example, Draper and Smith, 1966). The sum of the squares of the errors, S, for n observations is given by

$$S = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (G_{si} - b'G_i - a')^2 \tag{C18-5}$$

Differentiating S with respect to a' and b' and setting the derivatives equal to zero gives two equations in a' and b' which minimize S:

$$\sum (G_{si} - b'G_i - a')G_i = 0 \tag{C18-6a}$$

$$\sum (G_{si} - b'G_i - a') = 0 \tag{C18-6b}$$

where the summations apply to the same range as in Eq. C18-5. Solving for b' and a' gives

$$b' = \frac{\sum G_i G_{si} - \left[\left(\sum G_i\right)\left(\sum G_{si}\right)\right]/n}{\sum G_i^2 - \left(\sum G_i\right)^2/n} \qquad \text{(C18-7a)}$$

$$a' = \left[\sum G_{si} - b' \sum G_i\right]/n \qquad \text{(C18-7b)}$$

C18.2 Annual Rating Curves and Prediction of Natural Sediment Yield Derivation of Annual Rating Curve

To understand how annual sediment yield can be related to annual runoff, the storm hydrograph illustrated in Figure C18-1 is analyzed. The total sediment yield for the event is given by

$$\forall_{si} = \int_o^{t_{di}} Q_s dt \qquad \text{(C18-8)}$$

where $\forall_{si}$ represents the sediment yield delivered by the $i^{\underline{th}}$ storm, t_{di} is the storm duration, and Q_s is the instantaneous sediment discharge. It is assumed that Q_s can be related to water discharge, Q, by a power law of the form of Eq. C18-1.

Substituting Eq. C18-1 into C18-8 gives

$$\forall_{si} = a\int_o^{t_{di}} Q^b dt \qquad \text{(C18-9)}$$

As shown in Fig. C18-2, the storm hydrograph can be represented by the dimensionless quantities Q_* and t_*. Upon substitution Eq. C18-11 becomes

$$\forall_{si} = at_{di}\left(\frac{\forall_i}{t_{di}}\right)^b \int_o^1 Q_*^b(t_I)dt_I \qquad \text{(C18-10)}$$

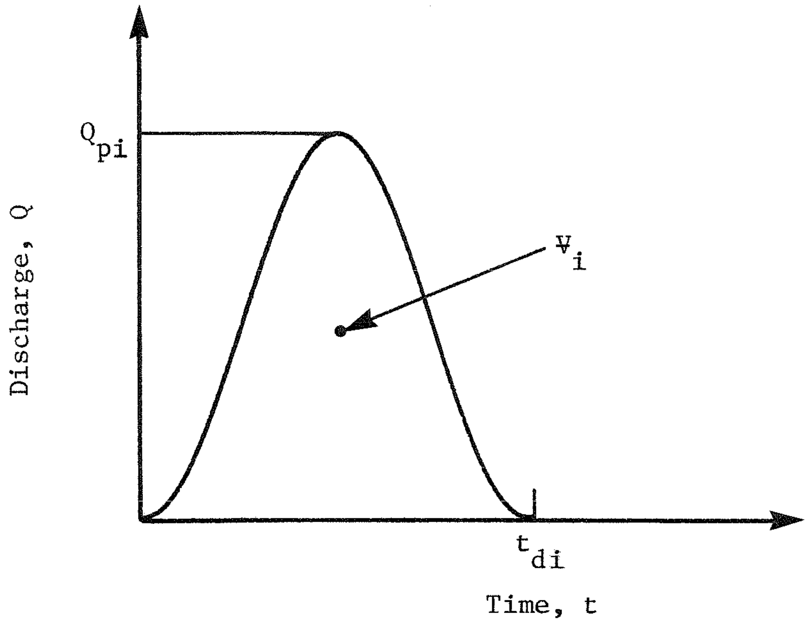


Figure C18-1. Hypothetical storm hydrograph for storm i.

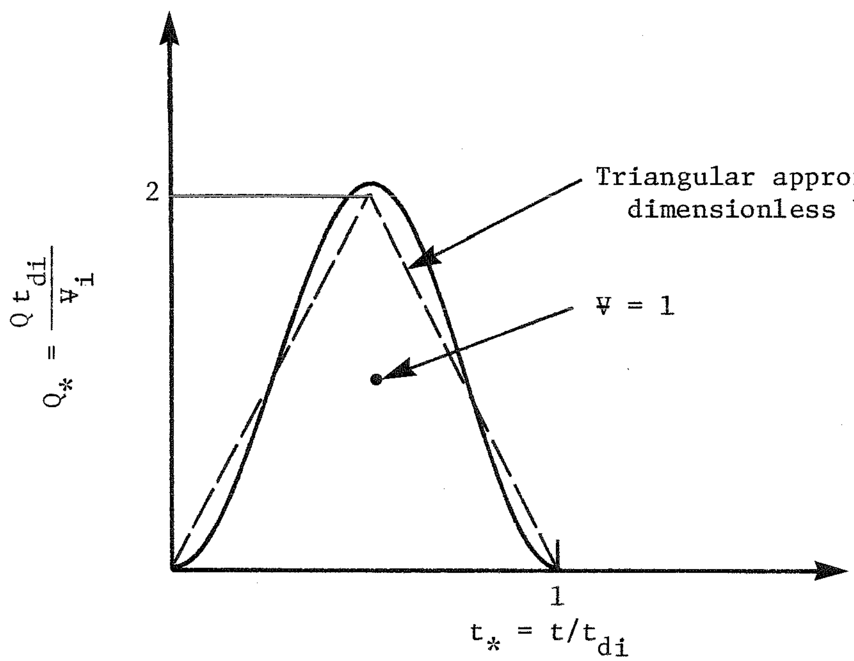


Figure C18-2. Dimensionless representation of storm hydrograph i.

where $\mathcal{V}_i$ represents the runoff volume of the storm. Rearranging,

$$\mathcal{V}_{si} = \left(\frac{aI}{t_{di}^{b-1}} \right) \mathcal{V}_i^b \qquad \text{(C18-11)}$$

where

$$I = \int_0^1 Q_*^b(t_I)\,dt_* \qquad \text{(C18-12)}$$

If, for a given station, all storm hydrographs have approximately the same form, then I will be constant. For example, if the hydrograph can be approximated by a triangle, as shown in Fig. C18-2, then I is given by

$$I = \frac{2^b}{b+1} \qquad \text{(C18-13)}$$

For the typical range, $1 \leq b \leq 2$, the value of I would range, $1 \leq I \leq 1.33$. From figures such as Fig. C3-8 and Fig. C4-10, it can be seen that the triangular assumption is reasonable for many stations in southern California.

If we wish to predict the sediment yield for a given year then we may examine a sequence of storm hydrographs. Two types of sequences are illustrated in Fig. C18-3 and considered below. In each case the dimensionless shape of each storm, Q_*, is assumed to be the same, and therefore I is constant.

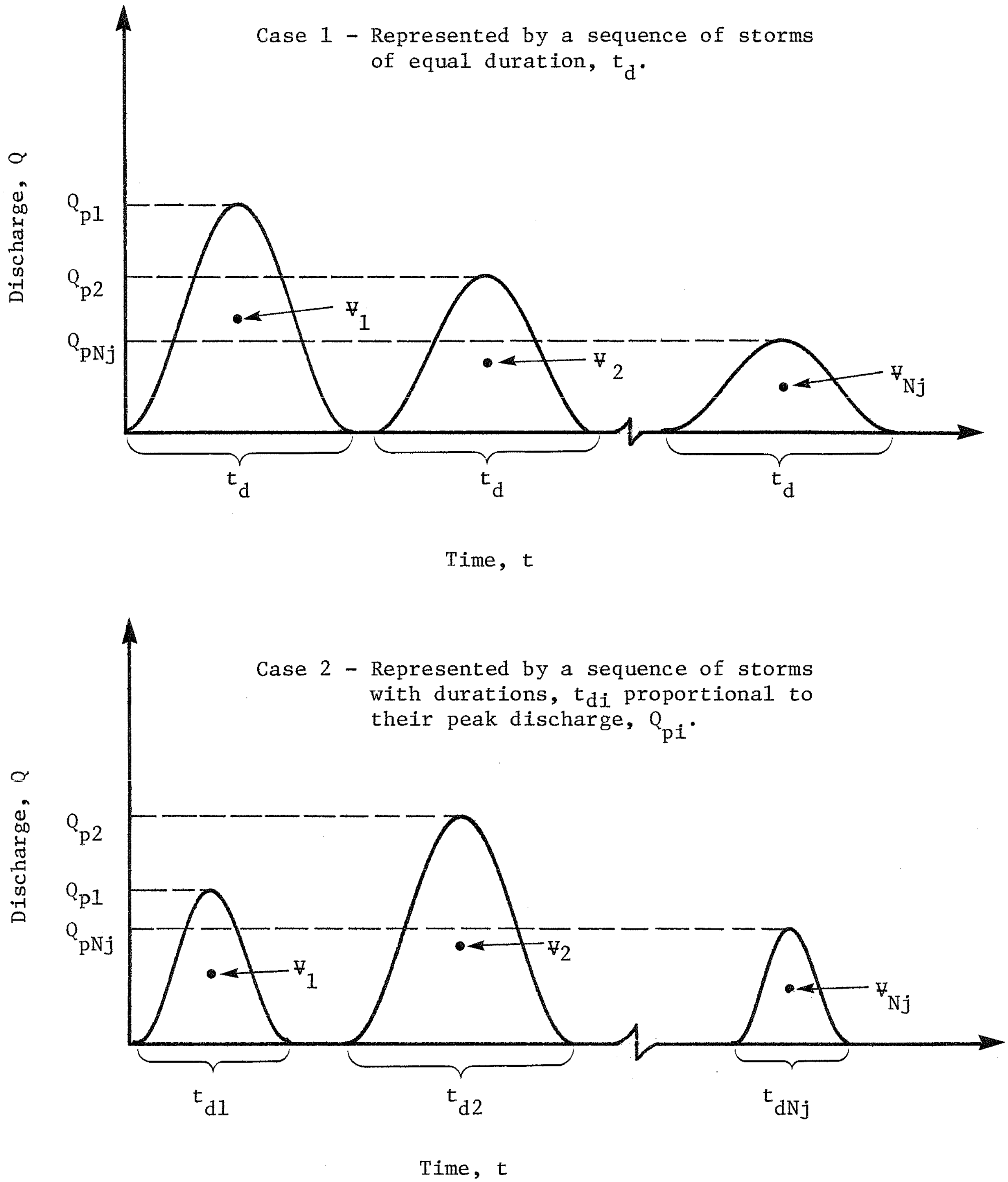


Figure C18-3. Two hypothetical annual sequences of storm hydrographs, where N_j is the number of storms for year j.

Case 1

For each storm event, the duration is the same, and therefore all of the t_{di}'s can be replaced by the constant t_d. Equation C18-11 can then be replaced by

$$Ұ_{si} = A'Ұ_i^b \qquad \text{(C18-14)}$$

where $A' = aI/t_d^{b-1}$ is constant.

Case 2

For this case, the duration of each event is assumed to be proportional to the peak discharge. Therefore, the storm duration can be related to the runoff volume by

$$t_{di} = CҰ_i^{1/2} \qquad \text{(C18-15)}$$

where c is an arbitrary constant. In this case, Eq. C18-11 can be replaced by

$$Ұ_{si} = A'Ұ_i^{\frac{b+1}{2}} \qquad \text{(C18-16)}$$

where $A' = aI/C^{b-1}$ is again a constant.

Both Eq. C18-14 and Eq. C18-16 can be represented in the general form

$$\hat{Ұ}_{si} = A'Ұ_i^B \qquad \text{(C18-17)}$$

where A' and B are constants. For a typical value of b = 1.6, we have

$$\text{Case 1} \quad \hat{\forall}_{si} = A'\forall_i^{1.6} \tag{C18-18a}$$

$$\text{Case 2} \quad \hat{\forall}_{si} = A'\forall_i^{1.3} \tag{C18-18b}$$

Flow sequences, such as Fig. C3-8, illustrate that the rivers in southern California probably lie somewhere between cases 1 and 2. The storm durations are probably not totally uncorrelated with the storm volumes; however, neither are they directly proportional to the peak discharge.

The last piece of the puzzle is the relationship between the annual sediment yield and the annual runoff. To find this relation, the storm runoffs are first related to the annual runoff by

$$\forall_i = p_i \forall_j \tag{C18-19}$$

where $\forall_j$ represents the total annual runoff for the $j^{\underline{th}}$ year and p_i is the fraction thereof which makes up the $i^{\underline{th}}$ event. Substituting Eq. C18-19 into C18-17 and summing over the number of storms in a year, N_j, gives

$$\forall_{sj} = A'\left(\sum_{i=1}^{N_j} P_i^B\right)\forall_j^B \tag{C18-20}$$

where $\forall_{sj}$ is the total annual sediment volume, for the $j^{\underline{th}}$ year.

Letting $P_j = \sum_{i=1}^{N_j} P_i^B$, Eq. C18-30 can be represented by

$$¥_{sj} = P_j A' ¥_j^B \qquad \text{(C18-21)}$$

Table C18-1 gives some typical values of P_j for the values of B given in Eqs. C18-18a and C18-18b.

In fitting a curve that would estimate $¥_{sj}$, it is desirable to find a technique which, for any value of $¥_j$, would predict an average value of $¥_{sj}$. The model has the same form as Eq. C18-3, but a different set of equations is used to solve for the constants. Letting $A = \bar{P}A'$, the predictive model can be represented by

$$¥_{sj} = 10^{\varepsilon_j} A ¥_j^B \qquad \text{(C18-22)}$$

Minimizing with respect to B gives an equation of the exact form of Eq. C18-6a. However, Eq. C18-6b is replaced by an equation that guarantees that the arithmetic mean of $¥_s$; will be preserved rather than the geometric mean. The two equations in A and B are

$$\sum_{j=1}^{m} (\log ¥_{sj} - B \log ¥_j - \log A) = 0 \qquad \text{(C18-22a)}$$

$$\sum_{j=1}^{m} (¥_{sj} - A¥_j^B) = 0 \qquad \text{(C18-22b)}$$

where m represents the number of years of record. Since A and B cannot be solved for directly, an iterative routine was written to solve for these constants.

TABLE C18-1

Typical Values of P_j in Equation C18-21
for Various Combinations of Storms, p_i

N_j	p_i	$P_j = \sum_{i=1}^{N_j} p_i^B$	
		For $B = 1.3$	For $B = 1.6$
1	$p_1 = 1.0$	1.0	1.0
2	$p_1 = .9,\ p_2 = .1$	0.92	0.87
2	$p_1 = .75,\ p_2 = .25$	0.85	0.74
2	$p_1 = p_2 = .5$	0.81	0.66
3	$p_1 = .8,\ p_2 = p_3 = .1$	0.85	0.75
3	$p_1 = .5,\ p_2 = p_3 = .25$	0.74	0.55
4	$p_1 = p_2 = p_3 = p_4 = .25$	0.66	0.44
10	$p_1 = \ldots = p_{10} = .1$	0.50	0.25

Case Study - Santa Clara River

For the Santa Clara River at Montalvo (11114000) the instantaneous rating curve for suspended sediment derived from the method described in Section C18.1 is

$$\hat{Q}_s = 24.4Q^{1.73} \tag{C18-24}$$

Thus, a = 24.4 and b = 1.73. The correlation coefficient of the logarithms of Q_s and Q is 0.942.

Using Eq. C18-24, annual suspended sediment yields were generated using daily flows from the water years 1950 to 1967. From this synthesized data and USGS estimates of suspended sediment yield for 1968 to 1976, the annual rating curve from the method described above is

$$\hat{V}_s = 983V^{1.53} \tag{C18-25}$$

where V is the annual storm runoff and V_s is the annual storm sediment yield (see Section C4.6). Thus A = 983 and B = 1.53. The correlation coefficient between log $\hat{V}_s$ and log V_s is 0.990, indicating that P_j's do not vary greatly.

If the river were in the category of Case 1, B would be equal to b = 1.73. If the river were in the category of Case 2, B would equal (b + 1)/2 = 1.36. The observed value of B indicates that some intermediate case probably exists in nature, for this river.

Predicting Natural Sediment Yield

If, as postulated in Section C1, the instantaneous sediment rating curve for a station is not greatly altered by the presence of man, then the natural annual sediment yield can be estimated from the predicted natural water yield. If P_j is approximately the same for the actual storm flows and the natural flows, then for the natural conditions we have, from Eq. C18-21

$$\mathbb{V}_{sj}(\text{nat}) = P_j A' \left[\mathbb{V}_j(\text{nat})\right]^B \qquad \text{(C18-26)}$$

where $\mathbb{V}_{sj}(\text{nat})$ and $\mathbb{V}_j(\text{nat})$ refer to natural annual sediment yield and water runoff, respectively. Eq. C18-26 can be rewritten as

$$\mathbb{V}_{sj}(\text{nat}) = \left[\frac{\mathbb{V}_j(\text{nat})}{\mathbb{V}_j(\text{act})}\right]^B P_j A' \left[\mathbb{V}_j(\text{act})\right]^B \qquad \text{(C18-27)}$$

where $\mathbb{V}_j(\text{act})$ is the actual runoff. Therefore, the natural sediment yield for a particular year can be approximated by

$$\mathbb{V}_{sj}(\text{nat}) = \left[\frac{\mathbb{V}_j(\text{nat})}{\mathbb{V}_j(\text{act})}\right]^B \mathbb{V}_{sj}(\text{act}) \qquad \text{(C18-28)}$$

where $\mathbb{V}_{sj}(\text{act})$ is the actual sediment yield. Equation C18-28 has been used for all predictions of natural suspended sediment delivered by storms (where the $\mathbb{V}_j(\text{nat})$'s and $\mathbb{V}_j(\text{act})$'s are taken as natural and actual annual storm runoffs, respectively, and the $\mathbb{V}_{sj}(\text{act})$'s are the actual annual suspended sediment yields delivered by storms) except where $\mathbb{V}_j(\text{act})$ is zero. For the cases where $\mathbb{V}_j(\text{act})$ is zero, the annual rating curve has been used directly with natural storm runoff.

C18.3 Non-Linear Curve-Fitting Technique

In Eq. C18-2 of Section C18.1, it was assumed that errors in predicting sediment transport rates would be relative rather than absolute. For certain other types of hydrologic data, it makes more sense to assume that errors are absolute rather than relative. In this case, the observed value of some dependent variable y_i, can be related to the predict value $\hat{y}_i$, by

$$y_i = \hat{y}_i + \varepsilon_i \tag{C18-29}$$

If the predicted value, $\hat{y}_i$, is in turn related to some dependent variable, x_i, by a three parameter power-law nonlinear equation, then Eq. C18-29 can be rewritten as

$$y_i = ax_i^b + c + \varepsilon_i \tag{C18-30}$$

where a, b, and c are the three parameters. For those cases where b = 1, this model is the same as that used for ordinary linear regression.

To solve for a, b, and c, we again let S equal the sum of the squares of the error terms

$$S = \sum\varepsilon_i^2 = \sum(y_i - ax_i^b - c)^2 \tag{C18-31}$$

Differentiating with respect to a, b, and c, and setting the derivations equal to zero gives

$$\sum(y_i - ax_i^b - c)x_i^b = 0 \qquad \text{(C18-32a)}$$

$$\sum(y_i - ax_i^b - c)x_i^b \log x_i = 0 \qquad \text{(C18-32b)}$$

$$\sum(y_i - ax_i^b - c) = 0 \qquad \text{(C18-32c)}$$

after simplifying. When $b = 1$, then Eq. C18-32b is eliminated and Eqs. C18-32a and C18-32c take on the same form as Eqs. C18-6, i.e., that of ordinary linear regression.

Equations C18-32 can be rewritten so that a and c are expressed in terms of b. In order to solve for b, some numerical scheme is required. A Newton-Raphson iterative method was devised to solve the equation on the computer. The program was used for estimating missing runoff data, and to develop the equations used to calculate percolation losses on the Santa Margarita and Tijuana rivers.

C19 Supporting Data

This section contains annual flow data used for calculation of natural flows on seven of the eight moderately developed basins. Since natural flows were not calculated for the Calleguas Creek basin, this basin has not been included. Annual flow values, given in million m^3, are compiled in the following tables:

C19-1 Ventura River basin
C19-2 Santa Clara River basin
C19-3 Santa Margarita River basin
C19-4 San Luis Rey River basin
C19-5 San Dieguito River basin
C19-6 San Diego River basin
C19-7 Tijuana River basin

The tables follow.

Table C19-1

VENTURA RIVER BASIN FLOWS IN MILLION CUBIC METERS.
STATIONS: 11118500-VENTURA R AND 11116000-MATILIJA CR.

WATER YEAR	VENTURA RIVER	VENTURA+ DIVERS'N	MATILIJA CREEK
1934	35.200	40.040	3.805
1935	49.458	54.150	6.791
1936	30.012	35.060	4.112
1937	133.376	138.400	16.757
1938	234.580	239.300	28.270
1939	23.391	28.820	3.380
1940	13.398	18.980	2.779
1941	316.252	321.330	38.596
1942	27.388	32.400	5.308
1943	168.402	174.090	19.691
1944	92.233	98.470	12.177
1945	37.114	43.780	5.939
1946	28.788	35.950	6.351
1947	14.057	21.440	3.707
1948	0.057	3.220	0.938
1949	0.196	2.970	1.416
1950	3.283	7.290	2.009
1951	0.000	2.060	0.730
1952	154.083	158.940	17.854
1953	10.418	17.440	3.448
1954	11.309	17.430	3.117
1955	1.106	6.070	1.661
1956	12.334	18.550	3.090
1957	2.715	7.170	2.265
1958	198.827	204.130	31.767
1959	7.358	13.410	4.662
1960	1.686	5.250	1.289
1961	0.258	1.980	0.807
1962	72.911	80.190	18.560
1963	3.213	8.760	2.373
1964	0.274	4.910	1.568
1965	2.222	7.610	2.312
1966	45.285	52.430	17.112
1967	34.494	44.050	18.644
1968	6.954	15.200	2.586
1969	308.532	314.030	67.353
1970	12.332	20.260	4.693
1971	13.959	20.380	5.568
1972	3.697	10.740	3.080
1973	58.205	65.190	20.574
1974	16.699	22.450	4.400
1975	16.514	23.480	5.835

Table C19-2

SANTA CLARA RIVER BASIN FLOWS IN MILLION CUBIC METERS.
INPUTS TO EQUATIONS C4-3 AND C4-4.

WATER YEAR	MONTALVO ACT.FLOW	SATICOY DIVERS'N	L.PIRU YIELD	DIVERTED YIELD
1928	19.366	0.0	-1.000	-1.000
1929	36.265	5.773	-1.000	-1.000
1930	19.119	9.153	-1.000	-1.000
1931	19.489	8.844	-1.000	-1.000
1932	164.055	11.837	-1.000	-1.000
1933	29.908*	12.372	-1.000	-1.000
1934	67.757*	9.819	-1.000	-1.000
1935	126.863*	23.206	-1.000	-1.000
1936	59.048*	15.922	-1.000	-1.000
1937	334.857*	24.839	-1.000	-1.000
1938	582.437*	16.840	-1.000	-1.000
1939	82.304*	16.708	-1.000	-1.000
1940	33.273*	20.710	-1.000	-1.000
1941	1083.993*	0.488	-1.000	-1.000
1942	84.894*	0.0	-1.000	-1.000
1943	419.617*	0.0	-1.000	-1.000
1944	405.441*	2.413	-1.000	-1.000
1945	100.133*	5.844	-1.000	-1.000
1946	96.768*	21.268	-1.000	-1.000
1947	55.949*	28.072	-1.000	-1.000
1948	0.0 *	9.627	-1.000	-1.000
1949	2.703*	6.826	-1.000	-1.000
1950	6.723	11.960	-1.000	-1.000
1951	0.0	0.0	-1.000	-1.000
1952	236.831	31.290	-1.000	-1.000
1953	4.083	26.952	-1.000	-1.000
1954	15.258	24.579	-1.000	-1.000
1955	1.166	14.865	-1.000	-1.000
1956	17.503	21.166	3.219	0.0
1957	6.932	16.129	0.617	0.0
1958	343.529	92.005	97.175	16.665
1959	23.831	44.628	8.795	3.824
1960	0.408	17.598	0.0	0.691
1961	0.566	6.778	0.0	0.0
1962	276.920	59.912	84.026	9.140
1963	7.672	27.598	1.283	4.983
1964	5.822	13.379	0.691	1.505
1965	9.362	20.018	1.517	0.0
1966	190.082	66.297	53.768	6.019
1967	140.865	111.350	55.618	13.778
1968	12.064	56.333	3.207	0.0
1969	1097.196	117.689	88.799	29.333
1970	64.315	97.132	11.916	34.785
1971	82.262	79.558	20.636	5.600
1972	36.647	37.010	14.865	4.429
1973	247.686	78.484	34.904	10.402
1974	77.229	74.733	18.232	5.434
1975	64.512	71.630	19.514	5.815

*Estimated

NOTE: Negative one (-1.000) indicates column heading is not applicable.

Table C19-2 (cont.)

SANTA CLARA RIVER BASIN FLOWS IN MILLION CUBIC METERS.
INPUTS TO EQUATIONS C4-3 AND C4-4.

WATER YEAR	CASTAIC NAT FLOW	CASTAIC ACT FLOW	SESPE CREEK	PIRU CR. NAT.FLOW
1928	-1.000	-1.000	24.053	12.895
1929	-1.000	-1.000	23.313	11.888
1930	-1.000	-1.000	22.203	11.324
1931	-1.000	-1.000	20.846	15.235
1932	-1.000	-1.000	102.380	63.577
1933	-1.000	-1.000	39.719	12.716
1934	-1.000	-1.000	64.142	20.273
1935	-1.000	-1.000	103.120	40.618
1936	-1.000	-1.000	65.042	17.106
1937	-1.000	-1.000	210.928	83.574
1938	-1.000	-1.000	294.806	154.385
1939	-1.000	-1.000	56.803	45.836
1940	-1.000	-1.000	40.089	23.296
1941	-1.000	-1.000	463.302	271.464
1942	-1.000	-1.000	52.103	38.614
1943	-1.000	-1.000	210.311	124.156
1944	-1.000	-1.000	176.513	150.187
1945	-1.000	-1.000	67.176	41.241
1946	-1.000	-1.000	79.499	38.782
1947	-1.000	-1.000	55.927	34.044
1948	-1.000	-1.000	9.819	7.953
1949	-1.000	-1.000	11.188	7.221
1950	-1.000	-1.000	20.846	8.721
1951	-1.000	-1.000	4.342	2.891
1952	-1.000	-1.000	185.271	94.646
1953	-1.000	-1.000	27.544	16.530
1954	-1.000	-1.000	40.816	18.785
1955	-1.000	-1.000	21.043	14.251
1956	-1.000	-1.000	36.512	13.642
1957	-1.000	-1.000	29.333	13.630
1958	-1.000	-1.000	279.017	115.924
1959	-1.000	-1.000	39.324	23.066
1960	-1.000	-1.000	15.900	9.276
1961	-1.000	-1.000	11.027	7.734
1962	-1.000	-1.000	220.796	111.952
1963	-1.000	-1.000	20.390	11.755
1964	-1.000	-1.000	16.850	10.189
1965	-1.000	-1.000	32.614	13.482
1966	-1.000	-1.000	194.523	85.962
1967	-1.000	-1.000	193.782	92.229
1968	-1.000	-1.000	29.962	20.599
1969	-1.000	-1.000	573.946	246.872
1970	-1.000	-1.000	69.261	33.045
1971	4.580	0.0	82.373	48.119
1972	0.025	0.0	36.906	29.552
1973	4.231	5.156	199.210	69.392
1974	0.735	0.349	67.078	36.246
1975	0.074	0.0	80.597	38.797

Table C19-3

SANTA MARGARITA RIVER BASIN FLOWS IN MILLION CUBIC METERS.

WATER YEAR	11046000 YSIDORA	O'NEILL DITCH	VAIL INFLOWS	11044500 FALLBR'K	11044000 TEMECULA
1925	0.974	*	-1.000	5.255	5.563
1926	19.366	*	-1.000	15.419	11.817
1927	112.495	*	-1.000	104.971	90.539
1928	4.934	*	-1.000	6.760	6.106
1929	1.678	*	-1.000	5.958	6.081
1930	7.191	*	-1.000	10.707	9.510
1931	4.515	3.133	-1.000	6.069	6.130
1932	50.080	3.762	-1.000	45.516	39.842
1933	8.042	2.714	-1.000	8.560	8.067
1934	6.180	3.071	-1.000	6.007	5.662
1935	16.023	1.567	-1.000	9.597	8.289
1936	13.642	2.386	-1.000	8.721	8.363
1937	144.566	3.047	-1.000	96.595	75.071
1938	150.487	4.120	-1.000	112.359	88.725
1939	28.247	2.590	-1.000	23.251	18.589
1940	27.532	1.332	-1.000	20.624	16.973
1941	145.059	2.220	-1.000	102.504	73.134
1942	20.883	2.023	-1.000	19.440	16.134
1943	91.612	1.431	-1.000	71.407	58.739
1944	34.291	6.093	-1.000	26.952	22.487
1945	25.003	2.812	-1.000	19.193	15.974
1946	14.407	3.725	-1.000	13.753	12.976
1947	8.548	2.590	-1.000	10.731	9.597
1948	0.693	6.093	-1.000	8.190	7.302
1949	0.591	5.353	3.867	7.253	6.550
1950	0.0	2.356	2.346	4.823	5.131
1951	0.0	1.813	1.813	3.392	4.120
1952	58.764	0.242	15.493	57.987	41.544
1953	1.283	0.0	2.821	4.897	5.908
1954	9.547	2.442	6.909	9.301	8.820
1955	0.0	2.590	2.245	4.219	5.859
1956	0.0	0.475	1.690	2.159	4.626
1957	0.0	0.763	1.141	2.319	4.280
1958	37.461	1.443	13.639	23.683	22.154
1959	0.0	1.246	1.643	2.319	3.737
1960	0.0	0.841	1.337	2.072	4.046
1961	0.0	*	0.814	1.739	3.071
1962	0.0	*	1.590	4.909	4.946
1963	0.0	*	0.731	4.404	4.675
1964	0.0	*	0.810	1.986	2.652
1965	0.0	*	1.617	2.405	2.775
1966	8.425	*	5.717	11.583	9.276
1967	12.828	*	13.881	12.187	5.662
1968	0.0	1.620	1.798	2.492	2.886
1969	144.072	3.359	29.245	89.145	55.779
1970	5.736	0.875	2.340	7.302	5.785
1971	0.0	1.757	2.273	4.095	3.577
1972	0.0	1.079	2.404	4.058	3.256
1973	8.548	4.940	6.276	9.128	6.735
1974	3.108	2.542	2.608	6.464	5.316
1975	0.0	2.819	2.249	3.688	2.862
1976	0.0	2.102	2.583	4.638	3.651

*Data unavailable.

NOTE: Negative one (-1.000) indicates column heading is not applicable.

Table C19-4

SAN LUIS REY RIVER EASIN FLOWS IN MILLION CUBIC METERS.

WATER YEAR	11042000 OC'NSIDE	E. CANAL NAT FLOW	E. CANAL WASTE	11041100 BONSALL
1930	3.552	24.106	0.377	10.139
1931	0.0	6.820	0.053	4.342
1932	50.697	72.239	11.687	59.455
1933	5.896	15.416	0.152	11.126
1934	0.0	4.215	0.036	3.084
1935	6.414	12.604	0.179	10.546
1936	1.900	18.188	0.734	6.871
1937	127.174	129.432	9.862	135.561
1938	92.401	105.370	8.353	92.500
1939	23.769	34.956	0.817	27.273
1940	14.062	25.736	0.393	18.182
1941	101.492	100.471	5.376	101.838
1942	-1.000	37.768	0.104	30.615
1943	-1.000	51.806	0.376	44.295
1944	-1.000	34.443	0.046	19.539
1945	-1.000	31.774	0.096	16.406
1946	-1.000	22.530	0.134	15.443
1947	0.0	9.936	0.237	3.256
1948	0.0	6.142	0.223	0.287
1949	0.0	14.053	0.095	0.112
1950	0.0	5.887	0.072	0.0
1951	0.0	2.294	0.019	0.0
1952	1.283	48.369	14.443	6.945
1953	0.0	5.046	0.009	0.006
1954	0.0	15.435	1.707	0.0
1955	0.0	2.548	0.022	0.0
1956	0.0	2.527	0.206	0.0
1957	0.0	2.062	0.0	0.0
1958	3.355	40.556	5.493	6.316
1959	0.0	2.782	0.073	0.0
1960	0.0	2.394	0.0	0.002
1961	0.0	0.342	0.0	0.0
1962	0.0	4.141	0.005	0.005
1963	0.0	0.990	0.028	0.0
1964	0.0	1.911	0.011	0.0
1965	0.0	3.671	0.315	0.0
1966	0.997	14.193	1.880	3.688
1967	5.908	31.458	5.665	12.051
1968	2.627	3.432	0.192	2.886
1969	31.232	72.200	13.835	32.392
1970	4.404	3.643	0.144	3.836
1971	4.712	2.711	0.146	4.404
1972	4.996	1.716	0.0	3.713
1973	11.447	16.254	0.648	8.449
1974	10.423	4.463	0.542	7.635
1975	9.917	4.618	0.194	7.438
1976	-1.000	4.441	0.527	-1.000
1977	-1.000	1.541	0.148	-1.000

NOTE: Negative one (-1.000) indicates data are unavailable

Table C19-5

SAN DIEGUITO RIVER ANNUAL RESERVOIR STORAGE DATA(MILLION CUBIC METERS).

WATER YEAR	SUTHER. SPILL	SUTHER. INFLOW	HODGES SPILL	HODGES INFLOW
1919	-1.000	-1.000	0.0	4.236
1920	-1.000	-1.000	0.0	17.944
1921	-1.000	-1.000	0.0	1.832
1922	-1.000	-1.000	100.000	145.993
1923	-1.000	-1.000	0.0	19.872
1924	-1.000	-1.000	0.044	5.860
1925	-1.000	-1.000	0.049	2.135
1926	-1.000	-1.000	17.110	42.368
1927	-1.000	-1.000	182.431	193.288
1928	-1.000	-1.000	3.042	10.983
1929	-1.000	-1.000	0.039	10.482
1930	-1.000	-1.000	0.039	19.078
1931	-1.000	-1.000	0.031	5.934
1932	-1.000	-1.000	60.628	90.127
1933	-1.000	-1.000	6.113	21.316
1934	-1.000	-1.000	0.0	1.912
1935	-1.000	-1.000	0.0	10.509
1936	-1.000	-1.000	0.0	13.630
1937	-1.000	-1.000	160.240	200.937
1938	-1.000	-1.000	94.960	112.939
1939	-1.000	-1.000	34.132	49.519
1940	-1.000	-1.000	5.680	22.289
1941	-1.000	-1.000	193.551	221.166
1942	-1.000	-1.000	36.104	48.809
1943	-1.000	-1.000	40.066	57.604
1944	-1.000	-1.000	8.768	27.359
1945	-1.000	-1.000	5.394	21.944
1946	-1.000	-1.000	2.842	19.550
1947	-1.000	-1.000	0.025	1.781
1948	-1.000	-1.000	0.014	0.0
1949	-1.000	-1.000	0.011	1.423
1950	-1.000	-1.000	0.006	0.0
1951	-1.000	-1.000	0.0	0.0
1952	-1.000	-1.000	6.346	49.337
1953	-1.000	-1.000	0.038	1.895
1954	0.022	5.870	0.025	5.479
1955	0.030	0.879	0.004	0.0
1956	0.001	1.061	0.003	0.0
1957	0.002	1.150	0.006	0.0
1958	0.010	17.931	0.026	16.343
1959	0.0	0.968	0.005	0.577
1960	0.005	1.287	0.009	0.0
1961	0.0	0.163	0.006	0.0
1962	0.0	1.541	0.006	0.0
1963	0.0	0.389	0.003	0.0
1964	0.0	0.618	0.003	0.0
1965	0.0	1.438	0.000	0.262
1966	0.0	5.696	0.004	5.413
1967	0.0	10.886	0.014	11.997
1968	0.0	1.510	0.004	1.047
1969	0.0	22.416	0.0	28.118
1970	0.0	1.140	0.0	2.159
1971	0.0	1.664	0.0	1.648
1972	0.0	0.879	0.0	0.720
1973	0.0	7.914	0.0	4.844
1974	0.0	2.275	0.0	2.954
1975	0.0	3.340	0.0	0.039
1976	0.0	2.916	0.0	3.814
1977	0.0	0.976	0.0	3.346
1978	1.037	39.651	57.614	95.506

NOTE: Negative one (-1.000) indicates data are unavailable.

Table C19-6

SAN DIEGO RIVER ANNUAL FLOW DATA (MILLION CUBIC METERS).

WATER YEAR	11022500 (SANTEE)	SAN VIC. INFLOW	EL CAP. INFLOW	EL CAP. SPILL
1913	2.10	-1.00	-1.00	-1.00
1914	17.78	-1.00	-1.00	-1.00
1915	101.79	-1.00	-1.00	-1.00
1916	241.00	-1.00	-1.00	-1.00
1917	34.51	-1.00	-1.00	-1.00
1918	25.23	-1.00	-1.00	-1.00
1919	1.88	-1.00	-1.00	-1.00
1920	23.68	-1.00	-1.00	-1.00
1921	0.22	-1.00	-1.00	-1.00
1922	195.52	-1.00	-1.00	-1.00
1923	12.46	-1.00	-1.00	-1.00
1924	0.09	-1.00	-1.00	-1.00
1925	0.18	-1.00	-1.00	-1.00
1926	31.92	-1.00	-1.00	-1.00
1927	183.33	-1.00	-1.00	-1.00
1928	1.48	-1.00	-1.00	-1.00
1929	2.10	-1.00	-1.00	-1.00
1930	6.67	-1.00	-1.00	-1.00
1931	4.29	-1.00	-1.00	-1.00
1932	83.81	-1.00	-1.00	-1.00
1933	21.47	-1.00	-1.00	-1.00
1934	0.06	-1.00	-1.00	-1.00
1935	4.32	-1.00	13.06	0.0
1936	4.91	-1.00	16.60	0.0
1937	42.83	-1.00	126.47	0.0
1938	44.61	-1.00	93.15	24.25
1939	16.16	-1.00	42.98	5.22
1940	4.04	-1.00	23.42	0.0
1941	180.09	-1.00	211.62	137.59
1942	4.26	-1.00	32.26	0.0
1943	6.02	9.61	45.92	0.0
1944	7.84	7.82	39.03	0.0
1945	1.93	4.11	28.90	0.0
1946	2.99	5.64	16.75	0.0
1947	0.06	1.19	6.29	0.0
1948	0.70	0.30	3.07	0.0
1949	1.97	2.74	13.96	0.0
1950	0.08	1.86	4.63	0.0
1951	0.00	0.76	2.52	0.0
1952	17.29	16.96	70.23	0.0
1953	0.25	1.75	5.72	0.0
1954	4.58	3.62	20.12	0.0
1955	0.44	0.42	3.11	0.0
1956	0.24	0.10	2.22	0.0
1957	0.81	1.10	3.61	0.0
1958	10.05	14.25	50.72	0.0
1959	1.90	0.66	3.12	0.0
1960	3.51	0.91	3.50	0.0
1961	2.98	0.75	0.99	0.0
1962	6.97	1.39	5.63	0.0
1963	4.20	1.42	0.42	0.0
1964	1.46	4.77	2.43	0.0
1965	2.20	1.37	6.39	0.0
1966	14.23	5.46	18.16	0.0
1967	9.45	9.05	19.38	0.0
1968	2.23	2.29	0.90	0.0
1969	17.94	17.92	39.47	0.0
1970	3.27	2.16	1.79	0.0
1971	4.71	3.30	3.37	0.0
1972	5.04	1.48	1.32	0.0
1973	12.14	6.96	23.75	0.0
1974	8.73	3.45	4.29	0.0
1975	16.31	4.19	6.97	0.0

NOTE: Negative one (-1.00) indicates column heading is not applicable.

Table C19-7

TIJUANA RIVER BASIN FLOWS IN MILLION CUBIC METERS.
NOTE: -1.00 INDICATES DATA UNAVAILABLE.

WATER YEAR	MORENA IN	BARRETT IN	BARRETT OUT	DULZURA ACTUAL
1937	53.77	73.03	7.59	45.54
1938	34.95	33.55	13.57	40.83
1939	14.80	13.55	2.17	16.04
1940	14.78	10.40	0.13	7.35
1941	56.85	39.37	47.90	120.76
1942	8.42	7.86	6.30	15.51
1943	17.38	18.20	0.42	12.45
1944	20.82	17.64	0.21	18.23
1945	17.05	17.94	0.05	9.65
1946	9.79	7.92	0.02	4.14
1947	3.09	2.47	0.62	0.50
1948	1.21	1.52	0.50	0.37
1949	2.95	3.97	0.23	2.15
1950	0.73	0.77	0.01	0.05
1951	0.48	1.45	0.00	0.19
1952	11.00	24.16	0.01	10.93
1953	1.43	1.84	0.00	0.15
1954	2.83	6.27	0.00	3.10
1955	0.60	0.88	0.38	0.08
1956	0.26	0.73	0.13	0.04
1957	0.38	0.64	0.01	0.14
1958	3.34	11.12	0.01	4.02
1959	0.38	0.64	0.00	0.08
1960	0.40	0.53	0.00	0.0
1961	0.14	0.17	0.0	0.0
1962	0.35	1.05	0.0	0.29
1963	0.18	0.18	0.0	0.0
1964	0.20	0.16	0.0	0.0
1965	0.57	2.25	0.0	1.06
1966	1.57	6.34	0.00	3.90
1967	0.62	2.38	0.00	1.01
1968	0.29	0.41	0.00	1.46
1969	8.57	18.36	0.0	8.84
1970	0.77	1.30	0.05	0.29
1971	0.82	0.85	0.0	0.19
1972	0.40	0.78	0.0	0.03
1973	2.34	8.20	0.0	4.17
1974	0.51	0.80	0.0	0.71
1975	0.45	1.24	0.0	0.58
1976	0.57	1.57	0.0	0.62

Table C19-7 (cont.)

TIJUANA RIVER BASIN FLOWS IN MILLION CUBIC METERS.
NOTE: -1.00 INDICATES DATA UNAVAILABLE.

WATER YEAR	RODRIG. IN	RODRIG. OUT	NESTOR ACTUAL	T.R.INT. BOUNDARY
1937	0.0	0.0	82.06	-1.00
1938	54.05	0.40	61.27	-1.00
1939	20.40	0.06	24.16	-1.00
1940	21.78	0.21	13.58	-1.00
1941	219.15	182.00	410.39	-1.00
1942	24.14	10.45	30.86	-1.00
1943	24.12	0.0	21.30	-1.00
1944	73.85	48.60	131.37	-1.00
1945	19.54	0.0	18.75	-1.00
1946	7.09	0.0	8.77	-1.00
1947	1.80	0.0	2.81	-1.00
1948	0.91	0.0	0.73	3.61
1949	4.41	0.0	6.51	8.41
1950	2.04	0.0	0.19	3.05
1951	1.45	0.0	0.0	0.10
1952	49.21	0.0	24.52	24.45
1953	1.87	0.0	0.0	0.10
1954	14.80	0.0	3.55	5.10
1955	1.49	0.0	0.0	0.54
1956	1.23	0.0	0.0	0.0
1957	1.18	0.0	0.04	0.12
1958	11.91	0.0	2.82	3.61
1959	1.11	0.0	0.11	0.0
1960	0.80	0.0	0.17	0.0
1961	0.67	0.0	0.0	0.0
1962	0.68	0.0	0.08	0.63
1963	0.31	0.0	0.01	0.33
1964	0.39	0.0	0.0	0.16
1965	6.48	0.0	0.68	3.17
1966	6.12	0.0	2.79	3.67
1967	1.61	0.0	0.26	0.93
1968	0.86	0.0	0.05	0.26
1969	10.09	0.0	4.63	7.69
1970	1.32	0.0	0.06	0.85
1971	0.79	0.0	0.0	0.19
1972	1.02	0.0	0.0	0.51
1973	5.10	0.0	0.08	1.54
1974	2.73	0.0	0.07	0.96
1975	0.88	0.0	0.06	1.22
1976	3.50	0.0	0.78	-1.00

C20 Update - The Storms of 1978

At the time the data analysis was performed for the moderately developed basins, only sediment data through the 1976 water year were available. On some of the southern rivers, this presented somewhat of a problem, because only a few or no high flows had occurred during the periods of record for the various rivers. The storms of 1978 provided some high flows, but the data were not available until after the first draft of this report was completed. This section presents some unpublished data that was obtained from the USGS, for comparison with the existing analysis.

The instantaneous suspended sediment rating curves for the Santa Margarita, San Luis Rey, San Diego, and Tijuana rivers, as presented in sections C6.6, C7.6, C9.6, and C10.6, respectively, are shown in Figures C20-1 through C20-4. The figures show both the older data and the 1978 data. For the first three rivers, the 1978 data is in excellent agreement with the older data. This point is borne out by the statistical comparison given in Table C20. On the Tijuana River, the highest data points are in fair agreement with the line, but other points suggest a more complicated rating curve would give better agreement than a simple power law. However, it was felt that the quantity of new data was not sufficient to warrant a new analysis.

Table C20

Instantaneous Sediment Rating Curves
(with and without 1978 data)

USGS Station	River		Samples	Correlation Coeff. of Logarithms	Coefficient* a	Exponent* b
11046000	Santa Margarita	without 1978	25	0.951	8.90	1.66
		with 1978	35	0.957	9.25	1.68
11042000	San Luis Rey	without 1978	18	0.985	26.0	1.78
		with 1978	24	0.985	24.5	1.73
11022500	San Diego	without 1978	27	0.970	8.73	1.58
		with 1978	39	0.959	7.56	1.61

*Rating curve is of the form $\hat{Q}ss = aQ^b$, where $\hat{Q}ss$ is the predicted instantaneous suspended sediment discharge, in tonnes/day and Q is instantaneous water discharge in m^3/s.

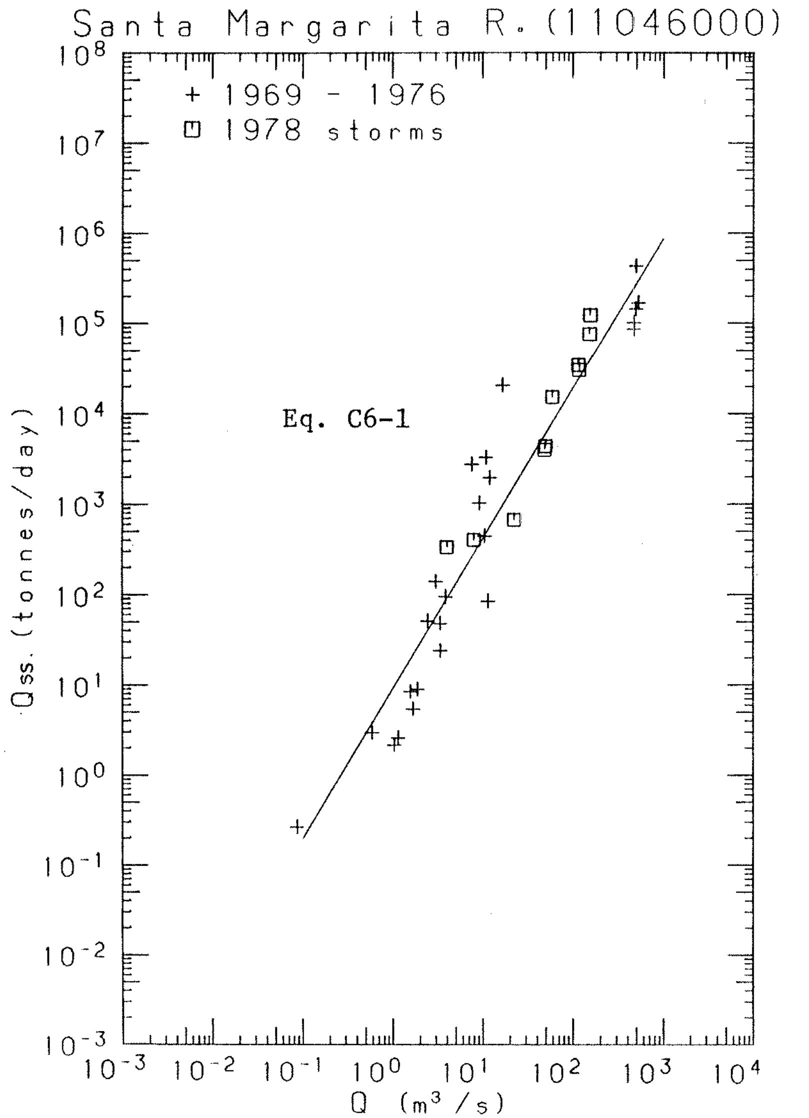


Figure C20-1 Relation of instantaneous suspended sediment discharge to water discharge at Santa Margarita River station 11046000.

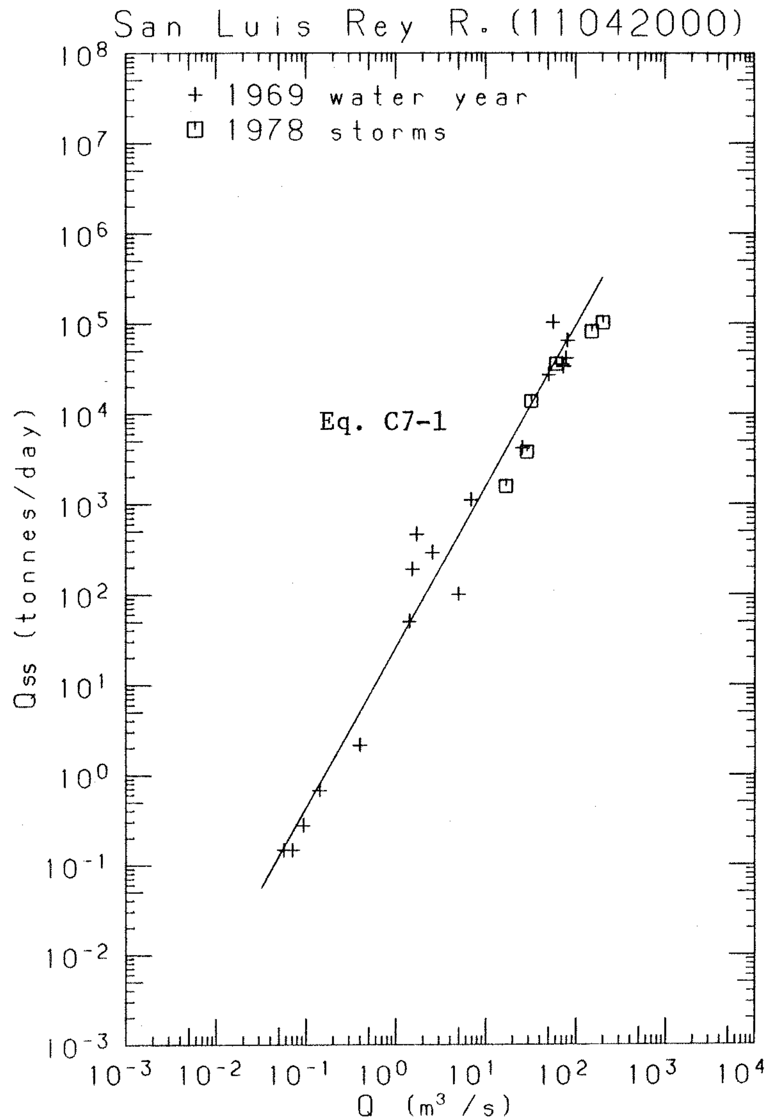


Figure C20-2 Relation of instantaneous suspended sediment discharge to water discharge at San Luis Rey River station 11042000.

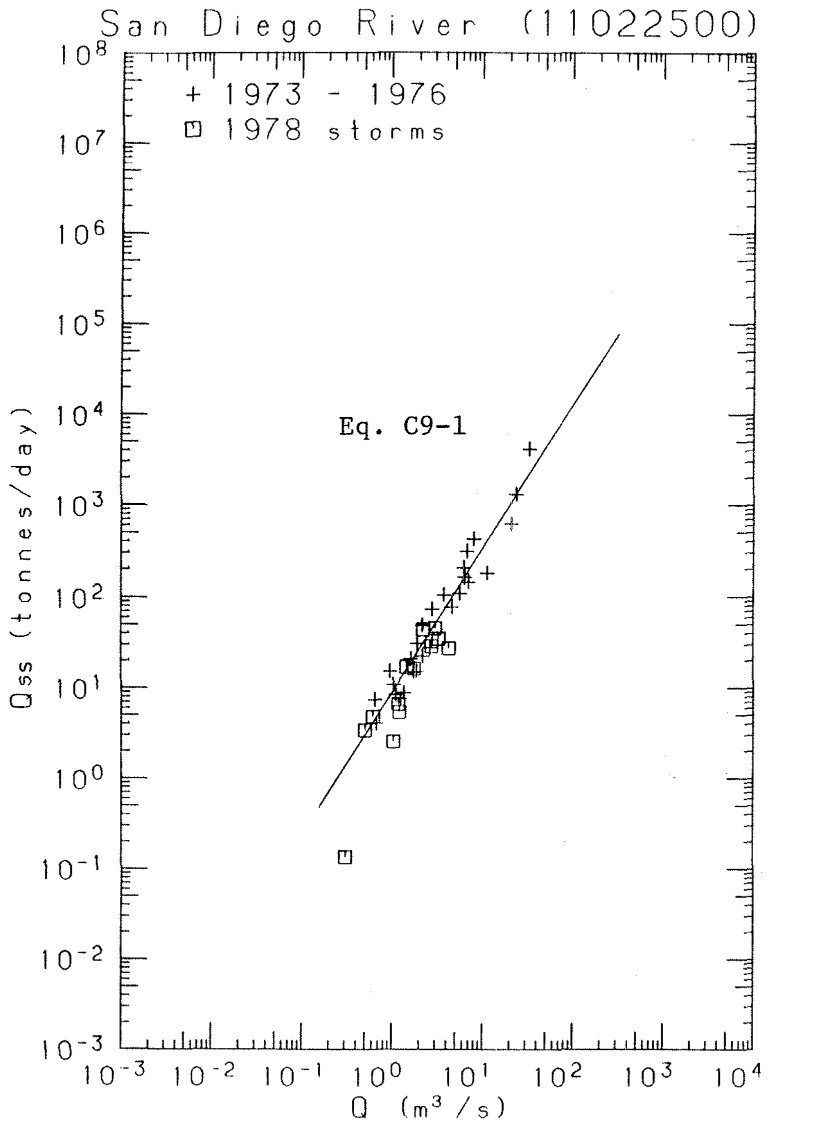


Figure C20-3 Relation of instantaneous suspended sediment discharge to water discharge at San Diego River station 11022500.

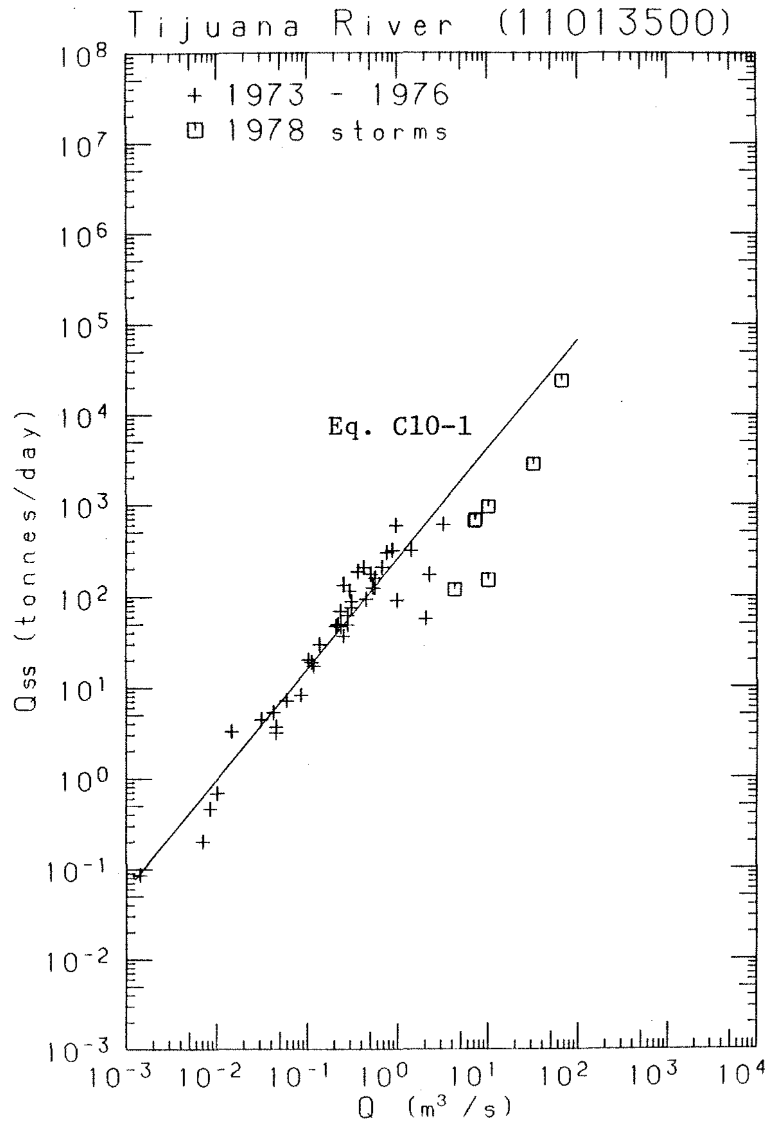


Figure C20-4 Relation of instantaneous suspended sediment discharge to water discharge at Tijuana River station 11013500.